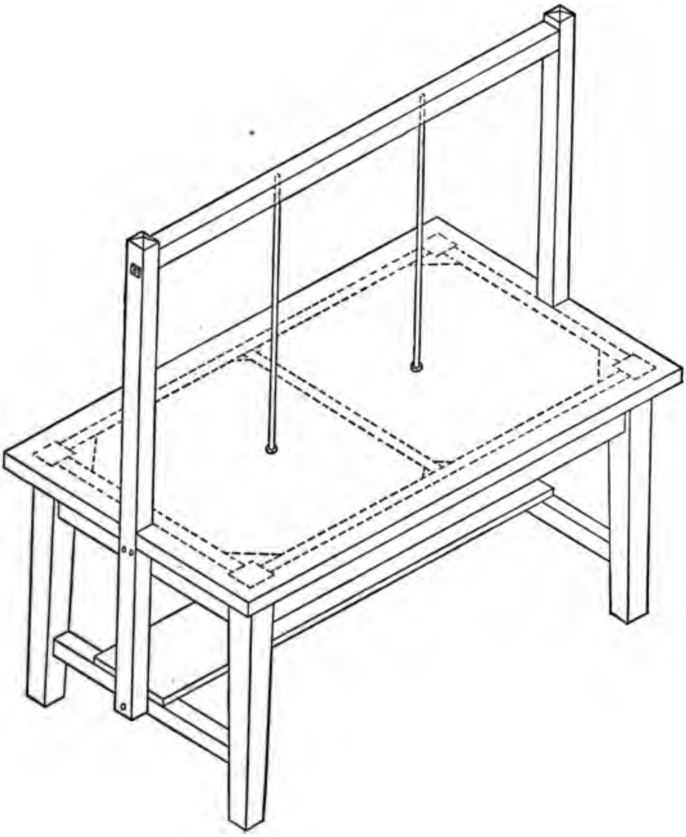
LABORATORY EXERCISES IN PHYSICS



Laboratory table, shown in isometric projection.
Length, 6 ft.; width, 3½ ft.; height of top, 3 ft.
Height of cross-bar above top, 3 ft. 4 in.

LABORATORY EXERCISES

IN

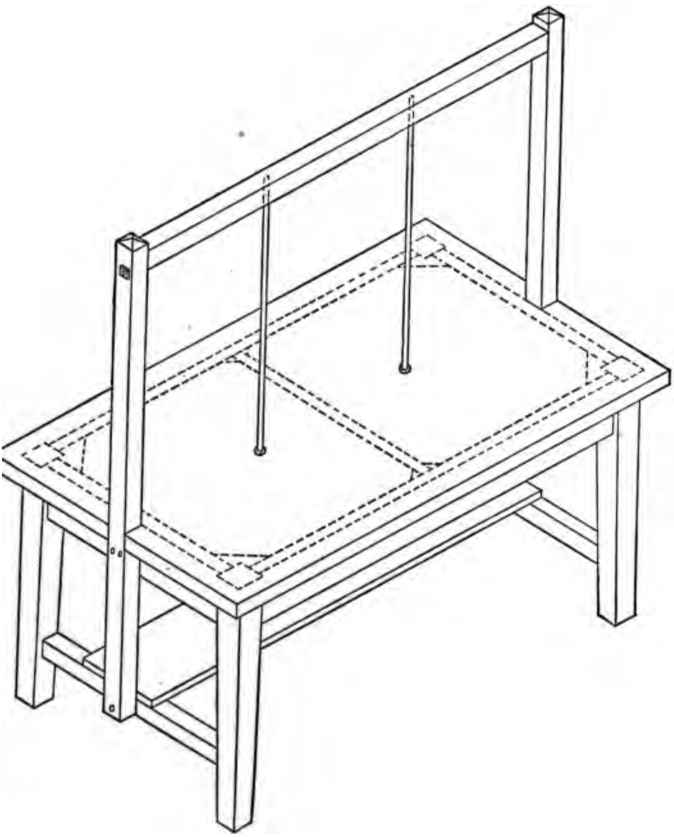
PHYSICS

FOR SECONDARY SCHOOLS

BY

GEORGE R. TWISS, B.Sc.
HEAD OF THE DEPARTMENT OF SCIENCE IN THE CENTRAL HIGH SCHOOL, CLEVELAND, OHIO

New York
THE MACMILLAN COMPANY
LONDON: MACMILLAN & CO., Ltd.
1902



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PREFACE

THE practicability and usefulness of these exercises, in connection with a course in elementary general physics, have been demonstrated by the test of actual use in the form of mimeographed sheets during a period of several years. They have reached their present form through a succession of revisions suggested by the needs of the author's pupils.

His classes have been large, they have represented both sexes and all grades of natural ability, and they have been limited by the school programme to working periods of forty-five minutes. The directions, worked out under these difficult conditions, have proved satisfactory.

Within the past two years the sheets have come into the hands of physics teachers in other and smaller schools, who have found them adapted to their needs also, and have encouraged the writer to prepare them for publication.

The experiments are selected and the directions written with regard to three purposes: *first*, to secure the thorough enforcement of some of the fundamental principles of the science, together with a view of the kind of thinking and experimentation by means of which the facts and principles of physics

have been established; *second*, to develop habits of precision in observation, thought, and expression; and *third*, to train the student in the acquisition of practical power and skill in the use of apparatus.

The author believes that physics, being a body of organized truth logically connected throughout, should be taught as such, — not as a collection of unrelated facts, or of facts only incidentally related. Therefore, in common with many other teachers of physics and with the authors of some of the best secondary text-books, he thinks that the laboratory experiments should be logically and intimately connected in a well-constructed teaching plan, which includes thorough text-book and recitation work, and also oral explanation with demonstrations at the lecture table. The plan should be so carried out that the student proceeds step by step from facts and principles that are already part of his mental property to those that are new to him.

Accordingly, while the exercises of this manual are mostly quantitative and every one sufficiently exacting for the last two of the three purposes stated above, they are rigidly restricted to those which have been found especially useful in giving secondary students a mastery of some of the great general principles which belong to the framework of the science. The teaching of principles by observation and induction, by deduction and experimental verification, is the controlling idea. To this end the laboratory exercise is but a means. To make it an end in itself is obviously a serious mistake.

Attention is respectfully directed to the following features of the work, which it is hoped will commend it for special consideration: —

1. Copious paragraph references at the head of each exercise direct the student to the co-related text of the most widely used modern class-books in physics.

2. Each exercise begins with a clear and concise statement of the purpose that it is intended to accomplish.

3. The directions for manipulation are meant to be *concise*, yet so *clear* and *explicit* that the student will rarely need to seek assistance elsewhere as far as mere manipulation is concerned. If he asks a question about operations, he can be sent back to these directions with great profit to his own independence and with a saving of much energy to the instructor, who can thus devote his time to the teaching of the subject instead of to profitless repetion of experimental details.

4. Pointed questions are frequently introduced to direct the observation and thought of the pupil while experimenting.

5. In drawing his inferences and reaching his conclusions, the student is aided by directions and questions which enable him to get over the difficult steps, and make the path plain so that he can proceed alone where it is less difficult.

6. Directions and suggestions are given for the form of record, carried out so as to train the student to the habit of arranging his notes in a manner such

that the contents can be easily referred to by himself and easily inspected by the teacher.

7. Due consideration is given the experimental errors of each exercise. Great precision is not possible in classes of beginners; but a careful consideration of the causes and limits of the more important errors gives a very valuable training in connection with observations which are only fairly accurate.

8. At the end of each exercise the student is directed to state the principle verified, or the conclusion reached, or the lessons learned from the experiment. Thus he is to begin with a definite purpose and to end with stating what he has accomplished.

9. Tables of physical constants and information for the teacher (who can easily get it elsewhere) are purposely omitted from the manual, *which is intended for the pupil.*

10. The number of exercises presented is smaller than in most of the manuals hitherto published. It is not attempted to give work illustrating every principle, nor to multiply methods of reaching a given result.

Thirty or thirty-five exercises selected equitably from the different parts of the subject is a number amply sufficient to secure the kind of training that the laboratory is designed to give. A small number of exercises worked "for all there is in them" is better than a large number carelessly and superficially performed. This is an idea which the author believes is growing in favor; and he has tried to be

in line with the reaction, which is surely coming, against overloaded text-books and manuals. Out of the forty-three exercises of this manual he has been wont to omit from seven to ten, dropping different ones in successive years.

Teachers will find much information that is nearly indispensable to them in any of the books of the following list : —

Elementary Practical Physics. Stewart & Gee. 3 vols. $4.85. The Macmillan Company.

Physical Manipulation. Pickering. 2 vols. $7.00. Houghton, Mifflin & Co.

Laboratory Arts. Threlfall. $1.50. The Macmillan Company.

The C. G. S. System of Units. Everett. $1.25. The Macmillan Company.

Instructions to Voluntary Observers. U. S. Weather Bureau.

The Barometer. U. S. Weather Bureau.

Methods of Glass Blowing. Shenstone. $0.80. Longmans & Co.

It gives me pleasure to acknowledge my indebtedness to my friend, Mr. Franklin Turner Jones, teacher of physics and chemistry in the South High School of Cleveland, who has read the work in manuscript and made many valuable and practical suggestions.

I am also much indebted to Professor Frank Perkins Whitman, of Western Reserve University, who has been kind enough to read the book in the proof-sheets, and to make some criticisms of which I have been glad to avail myself. Although I have used

all possible care to avoid mistakes and inconsistencies, any that may be found uncorrected must be laid at my own door.

My thanks are due several firms for the loan of electrotypes, or for permission to reproduce cuts from their catalogues. Figures 11, 18, 26, 38, and 40 are from the L. E. Knott Apparatus Co., Boston; 24 and 31a, from William Gaertner & Co., Chicago; 29 and 32, from J. R. Brown & Sharpe, Providence. Figure 5 is from Fairbanks, Morse & Co., Chicago; 16, from Henry J. Green, Brooklyn; 25, from the Chicago Laboratory Supply and Scale Co.; and 27, from Thomas W. Gleeson, Boston. Figures 35, 36, and 37 were kindly loaned by The Macmillan Company, from D. C. and J. P. Jackson's "Elementary Electricity and Magnetism." The originals of all the other cuts were drawn by myself, expressly for this book.

Suggestions and corrections from teachers using this manual will be greatly appreciated by the author, who will also be pleased to answer inquiries in regard to the exercises, or to the equipment and management of the laboratory. A small pamphlet containing such information as may be required by teachers in connection with the use of this book will be issued in case there appears a demand for it.

GEORGE R. TWISS.

CENTRAL HIGH SCHOOL,
CLEVELAND, OHIO,
September 1, 1902.

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TO THE STUDENT

THE LABORATORY

THE laboratory is your workshop. The value of the work done in it will depend upon the faithfulness with which you follow out the directions of the instructor and of this manual.

Punctuality. — Be prompt in beginning and stopping work at the proper signals. The time is short, and you cannot afford to lose a minute.

Attention. — Keep your attention fixed upon the work in hand, and listen carefully to every suggestion of the instructor. It is sometimes necessary to speak a few words to another student, but such conversations should be limited to that which is absolutely essential and held in a low undertone, as is customary in public libraries or large offices. Otherwise confusion and disorder will distract attention of both pupils and teacher, and good work cannot be done. No trifling can be tolerated. The individual freedom which must be allowed pupils in the laboratory is so much greater than that which is customary in the class room and study room that you will often be strongly tempted to abuse it in such a way as seriously to interfere with your own work and that of others. The effort that you must

make at self-control is one of the best features of the discipline that the laboratory training can give you. Do not compel the instructor to use repressive measures, but persist in governing yourself.

Order. — Preserve an orderly arrangement of apparatus while working. See that things are in the positions where they can be used most conveniently and expeditiously. Good and systematic work cannot be done with appliances in confusion.

Neatness. — Wipe off all dust from apparatus before beginning work. If the table or any piece of apparatus becomes soiled, or littered, or wet, it should be cleaned and dried immediately. See that you have dust cloths and a sponge at hand for the purpose. Do not leave papers or scraps of any kind upon the tables or floors, but deposit them in the receptacles provided.

Explanations. — Questions about the work should be asked of the instructor and not of a fellow-student. The latter may cause you to lose time by setting you on the wrong track; or he may deprive you of valuable mental exercise by telling you what you are able to think out for yourself.

Sinks. — Never throw anything into the sinks excepting water.

Preparation. — Study very carefully each exercise before the laboratory hour in which it is to be performed. Do not try to commit directions to memory, but *think out* everything they tell you to do. Try to comprehend the plan of the work, and picture to yourself just how you will carry it through. Where

your previous instruction by lecture and recitation work has prepared you for it, try also to think out the kind of results you may reasonably look for and the conclusions you may possibly reach. If the aim is to verify a law, see that you have the law well learned and know exactly what it means.

Prepare the page upon which your notes are to be taken. Have tabular forms ruled and spaces allotted for the different kinds of notes, so that no time may be lost in the laboratory in deciding where to put them, or in doing any writing that can as well be done outside. Every minute of time in the laboratory will be needed for the experimental work and the recording of the data there observed.

Carefulness. — Your work will be valueless unless accurate. Use conscientious care in making all observations. Obtain all values as accurately as is possible with the apparatus you are using. Record phenomena and numerical data at the moments when they are observed. *This is very important.* Record exactly what you observe, not what you think you should observe. Be absolutely and uncompromisingly honest with your own intellect, otherwise your time in the laboratory is almost thrown away. Do not nervously hurry, but work deliberately, steadily, and unremittingly, keeping the plan and purpose of the exercise constantly in mind. Eyes and hands should work together, both controlled by an alert mind.

DIRECTIONS FOR MAKING NOTES

1. Write your name, room number, and hour of recitation on the outside of your note-book.

2. Use the first page for a title-page and the next two for a table of contents in which you are to record the number of each exercise, together with its purpose or title, and the number of the page where it is recorded.

3. Begin the notes for each exercise or experiment on a new page, and leave a margin at least 1 cm. wide at each edge.

4. Number each left-hand page and the corresponding right-hand page with the same serial number; and at the top of each page place the date when the work is done.

5. Enter upon the left-hand pages with *sharp, hard* pencil the purpose or aim of the exercise, all observations, numerical data (in tabular form), all calculations and results, together with as much concerning apparatus and operations as may be necessary to furnish a basis for a complete report of your experiment, which is to be entered in ink upon the corresponding right-hand page. The entries on the left-hand pages must be neatly and systematically arranged, without crowding, and, *with the exception of purpose and calculations, no matter should be placed there except notes taken in the laboratory at the time when the observations are made.*

6. Enter in black ink, upon the right-hand page,

a clear, concise, and complete record of the exercise under the headings given below. *Do not copy the directions, but compose the record yourself.*

(*a*) **Purpose.** — Under this heading write a concise statement of what is to be accomplished by the exercise; thus, "The purpose of this exercise is to determine the specific heat of a metal;" or "The purpose of this exercise is to verify the law of Boyle."

(*b*) **Apparatus and Materials.** — Under this heading record a list of all pieces of apparatus and all the materials used. *Describe* any unfamiliar piece, or any new arrangement. Many of the pieces are numbered; and the *number* of each piece should be *recorded*, with its name, in order that it may be identified if it is to be used again. Make a *diagram* or *sketch* showing the parts of the apparatus and their arrangement while in use. The diagram should be neat and clear-cut, and its parts or points should be lettered. By referring to the lettered parts of the diagram the descriptions that follow can be much shortened.

(*c*) **Operations.** — Under this heading record in *clear*, *grammatical* sentences in the *indicative mode* each act that you perform as an essential part of the experiment. Avoid all unnecessary words. Do not repeat in one place anything expressed or directly implied in another. Do not hesitate to use the pronoun I (or we, if others worked with you).

(*d*) **Observations.** — Here record everything that happens which may have any relation to the laws

or properties which you are studying in the experiment or any bearing upon the conclusions to be derived. Exclude everything that is irrelevant.

(*e*) **Numerical Data.** — These should be recorded in neatly ruled tabular forms, different observed values of the *same quantity* in the *same vertical column*, *columns of related quantities near together*, and each under its proper heading, so that the meanings of the numbers and their relations to each other can be taken in at a glance. Numerical quantities should never be incorporated in the text of your notes, but set apart conspicuously so that it will not be necessary to search for them. *Final numerical results* should be underlined with red ink, or otherwise made *conspicuous;* and, if they are to be compared with others, should be placed near them.

(*f*) **Errors and Corrections.** — Under this heading enumerate the sources of error pertaining to each part of the apparatus and each operation in turn; and if corrections are to be made for these errors, indicate the method of correction and the reason for it.

(*g*) **Inferences or Lessons.** — Under this heading state what you have learned by the experiment, to what conclusion you have come, or what inferences you can draw as a result of the experimental study just completed. If the experiment was made to verify an established law, briefly explain upon what grounds you conclude that the law is verified by your results.

7. *Never make notes or calculations of any kind*

upon loose paper. Enter them all upon the left-hand pages of your note-book. The fundamental purpose of the note-book is the presentation of all such data in a form available for quick inspection by the teacher and ready reference by the student.

8. Do not erase numerical data. Quantities which appear erroneous or valueless may prove worthy of consideration. Enclose rejected matter in brackets, and write "Rejected" at the side of it.

9. Do not use common fractions. Express all fractional values in decimals.

10. Do not crowd the notes. Leave blank space between the different sections of the written matter and make the headings prominent.

TEXT-BOOK REFERENCES

The text-books referred to by paragraph numbers at the beginning of each exercise are named below: —

A . . . School Physics. Avery. Butler, Sheldon & Co.

C . . . Elements of Physics. Crew. The Macmillan Company.

C & C . High School Physics. Carhart and Chute. Allyn & Bacon.

GE . . Elements of Physics. Gage. Ginn & Co.

GP . . Principles of Physics. Gage. Ginn & Co.

H . . . A Brief Course in Physics. Hoadley. American Book Company.

H & W . Elements of Physics. Henderson and Woodhull. D. Appleton & Co.

J . . . Heat, Light, and Sound. Jones, D. E. The Macmillan Company.

J & J . Elementary Electricity and Magnetism. D. C. & J. P. Jackson. The Macmillan Company.

L . . . Elementary Mechanics. Lodge. The Macmillan Company.

S . . . Physics. Slate. The Macmillan Company.

T . . . Elementary Lessons in Electricity and Magnetism. Thompson. The Macmillan Company.

W & H. A Text-book of Physics. Wentworth and Hill. Ginn & Co.

REFERENCE BOOKS

Students are earnestly urged to read as much as they can from the books in the following list. Parts of some of them are too difficult to be thoroughly comprehended, but much of all of them is within reach of beginners, and will be of great assistance in extending the knowledge gained in the laboratory and class-room. A few of them can be read entire, and are sure to be not only inspiring, but fascinating as well.

Mechanics. Lodge. The Macmillan Company.

The Conservation of Energy. Stewart. D. Appleton & Co.

Heat as a Mode of Motion. Tyndall. D. Appleton & Co.

Lectures on Electricity. Tyndall. D. Appleton & Co.

Lectures on Electricity. Forbes. Longmans & Co.

Faraday as a Discoverer. Tyndall. D. Appleton & Co.

Elementary Electricity and Magnetism. D. C. and J. P. Jackson. The Macmillan Company.

Lessons in Electricity and Magnetism. S. P. Thompson. The Macmillan Company.

The Induction Coil in Practical Work. Wright. The Macmillan Company.

On Sound. Tyndall. D. Appleton & Co.

The Theory of Sound in Relation to Music. Blaserna. D. Appleton & Co.

Sound. Mayer. D. Appleton & Co.

Light. Mayer and Barnard. D. Appleton & Co.

Light, Visible and Invisible. S. P. Thompson. The Macmillan Company.

Six Lectures on Light. Tyndall. D. Appleton & Co.

History of Physics. Cajori. The Macmillan Company.

Experimental Science. Hopkins. Munn & Co.

LABORATORY EXERCISES IN PHYSICS

CHAPTER I

MEASUREMENTS

Exercise Number 1

LENGTH MEASUREMENT

References

A 17–20	C & C 7, 8	GP 1, 2	H & W 36–43
C 8, 9, 11	GE 2, 4–5	H 11–13	W & H 9, 10

Purpose. — The purpose of this exercise is to measure the length of the laboratory table.

Apparatus. — The apparatus consists of a meter rule, — graduated in centimeters (hundredths) and millimeters (thousandths) on one side, and in inches and eighths on the other, — a rectangular block, and a knife or pin.

Operations. — (*a*) Place the block at one end of the table, with one of its plane surfaces perpendicular to the upper surface of the table.

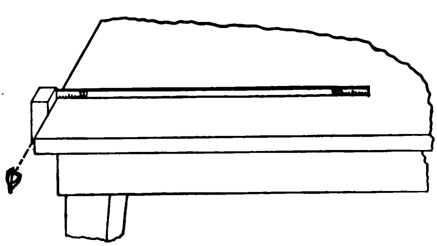

Fig. 1. — Showing the rule and block in position.

(*b*) Stand directly in front of the block, set the rule on edge, and bring one of the centimeter lines on the rule (*e.g.* the line marked 1) into coincidence with the *back edge* of the block.

(*c*) Adjust the rule parallel with edge of the table; and see that the 1 cm. line is still in place.

(*d*) With the knife, make a short, thin scratch at the point where the 99 cm. line meets the surface of the table.

(*e*) Move the rule along; again adjust it parallel with the table top edge, but with the 1 cm. line at the knife scratch, and make a new knife scratch at the 99 cm. line.

(*f*) Continue the process until the length of the table remaining to be measured is less than the 98 cm. of the rule; then, in a similar manner, read off the number of centimeters in the remainder, using the block, as before, to determine the position of the other end of the table.

(*g*) If the end of the table does not exactly coincide with one of the centimeter lines, note the number of additional millimeters between the nearest centimeter line on the left, and the millimeter line with which it does coincide.

If it does not coincide exactly with a millimeter line, estimate the fractional part of a millimeter remaining as 0.5 mm., if it is nearer to the middle of the millimeter space than to either end of that space. If the end of the table is nearer to either end than to the middle of the millimeter space, read the number of whole millimeters between the last

centimeter line and the millimeter line with which it most nearly coincides.

(*h*) Add up the numbers of centimeters and millimeters to get the total length of the table, expressing it in meters, hundredths, and thousandths.

For example, suppose that you have found it to be 98 cm. + 98 cm. + 98 cm. + 7 cm. + 5 mm. + 0.5 mm.; the total is 301.55 cm. or 3.0155 m.

(*i*) Make at least four more measurements in the same manner, at different distances from the front edge of the table; enter the results under the others; and find their average for the mean length of the table.

(*j*) In another column enter an equal number of measurements, made in the same manner, but with the inch side of the rule. If there is a remainder, less than an inch, estimate its value to the $\frac{1}{4}$ part of the $\frac{1}{8}$ inch divisions (that is, to $\frac{1}{32}$ inch). Obtain the mean as before, reducing it to inches and a decimal fraction of an inch.

(*k*) Reduce the mean value in inches and a decimal of an inch to meters and a decimal of a meter (divide by 39.37), and place the result beneath the mean value obtained with the metric side of the rule, so that these two mean values can be readily compared. If the work has been done with respectable accuracy, they will agree within 2 or 3 mm.

The individual measurements will agree closely with each other. If they do not agree fairly well, this will indicate large errors, or mistakes caused by carelessness, or that the table is slightly irregular in form.

Precision of Statement. — In a physical experiment

we should state the result numerically just as accurately as we are able to observe it. Hence, when we measure the thousandths of meters and estimate the ten-thousandths, we should retain the figure in the fourth decimal place, *even though it be a zero.* On the other hand, since this last figure represents a number of ten-thousandths that has been estimated, it is in doubt, and any that may follow it, being wholly unknown, should be rejected. In taking the mean of the individual measurements the same principle is to be observed. *In this and all subsequent work, retain the first doubtful figure and reject all that follow.*

Data.—The following form for the record is suggested ; but the student should always try to devise for himself neat and convenient forms for his results. The purpose of a record in tabular form is to make it easy to inspect and compare the quantities that are related to one another.

LENGTH OF TABLE —— —— SIDE [1]

MEASUREMENT	METERS	INCHES
1		
2		
3		
4		
5		
Mean		

Mean Length (measured in meters) m.
Mean Length (measured in inches and reduced) . . . . m.
Difference . . . . m.

[1] In the blanks, place the number of the table and the side measured, *e.g.* Table Number 1, North Side.

Precautions. — (*a*) In reading a rule or scale of any kind, keep the line of sight perpendicular to the edge of the scale at the point of reading, in order to avoid the errors of *parallax.*

(*b*) The first and last divisions of a scale, if at its ends, should not be used, as they are likely to be somewhat worn off.

Lessons. — The exercise is designed to teach the principles which underlie the use of scales in simple linear measurements, and to give practice in the use of metric units.

Additional Work. — If there is time for additional work, take a longer series of measurements, or measure the other three sides of the table, and from the mean length and mean width calculate the area in square meters.

NOTE. — If it is desired not to scratch the table, the teacher may supply a squared board, to be laid on top. In that case the measurements should be made upon the board just as directed for the table top.

EXERCISE NUMBER 2

DETERMINATION OF VOLUME

REFERENCES

A 20	C & C 8	GP 6	H & W 47–51
C 12, 13	GE 6	H 14, 16, 18	W & H 10

Purpose. — The purpose of this exercise is to determine the volume of a regular solid by three different methods: (*a*) by calipers and rule, (*b*) by the vernier slide caliper, and (*c*) by submersion in a graduate.

Part A

BY CALIPERS AND RULE

Apparatus. — A pair of calipers, a 30-centimeter rule, reading to millimeters, and a solid (say a cylinder of copper, brass, or aluminum) are used.

Operations. — The mean altitude, a, and the mean diameter, $2r$, are to be determined by measurement, and the volume, V, is to be calculated by the rule of geometry expressed in the formula, $V = \pi r^2 a$. ($\pi = 3.1416$.)

(*a*) Adjust the calipers so that their tips are just in contact with the opposite bases of the cylinder, the line joining the tips being parallel with the axis of the cylinder.

(*b*) Remove the calipers, being careful not to allow the tips to change their relative positions; and apply the tips to the rule, so that the inside edge of one tip is at the middle of one of the centimeter lines, and the line joining the tips is parallel with the edge of the rule. Read the position of the inside edge of the other tip, to the tenth of a millimeter, and record the distance between the tips in centimeters, tenths, and hundredths. The hundredths of centimeters (tenths of millimeters) are to be estimated by the eye. This can easily be done; thus, the smallest amount more than $\frac{1}{2}$ is .6, less than $\frac{3}{4}$, .7, and so on.

(*c*) In this manner, make and record at least five measurements of the altitude taken at different places.

(*d*) In a similar manner make the same number of measurements of the diameter, the lines between

the caliper tips being parallel with the bases of the cylinder.

(*e*) Record the individual measurements and their mean values in a tabular form similar to that used in Exercise 1. Compute and record the volume.

Part B

BY THE VERNIER SLIDE CALIPER

Apparatus. — The additional apparatus is the vernier slide caliper.

Operations. — Each dimension is to be measured at least twice; the individual and mean values are to be recorded in tabular form as before; and the mean volume is to be computed.

(*a*) Loosen the set screw, *s*; and, grasping the scale in the right hand, press the thumb against the little projection, *p*, below the vernier till the movable jaw withdraws from the fixed one. Now place the cylinder between the jaws; and, with the thumb on the projection, press the jaws together against the two bases of the cylinder, so that they are just in contact with the respective bases.

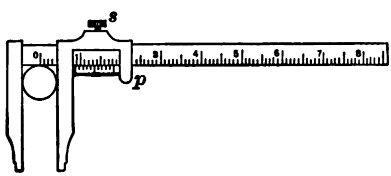

Fig. 2. — Vernier Slide Caliper.

(*b*) By means of the set screw, fasten the movable jaw in position, remove the cylinder, and take the reading of the caliper in accordance with the rule that follows.

(*c*) *To read the (metric) vernier slide caliper.* — Read and record the number of centimeters and whole millimeters from the zero of the scale to the zero of the vernier; and add the number of tenths of a millimeter in the remainder. This is denoted by the number of the line on the vernier which most nearly coincides with some line on the scale: *e.g.* if line number 3 on the vernier coincides with some line on the scale, the remainder is .3 mm.

In order to understand why this is so, notice that the vernier scale is 9 mm. long and is divided into 10 equal parts; hence, each vernier division is .9 mm. long. On the other hand each division of the fixed scale is 1.0 mm. long. Therefore when vernier line 3 coincides with some fixed scale line, vernier line 2 falls .1 mm. short of the fixed scale line next to the left of it. It is obvious also that vernier line 1 must fall .2 mm. short of the fixed scale line next to the left of it. Finally the vernier line 0 must fall .3 mm. short of the fixed scale line next to the left of it. But this space of .3 mm. is the fractional part of a millimeter that was to be measured. In general, if the coinciding vernier line is n, the distance from that line back to the vernier line 0 is $.9\,n$ mm.; and the distance back to the fixed scale line next to the left of the vernier line 0 is n mm. Now, $n - .9\,n = n$ tenths mm., the fractional remainder that was to be measured by means of the vernier. By reasoning precisely similar to that above, it may be made very clear in every case, that the number of the coinciding vernier line is the same as the number of tenths of a millimeter in the remainder. If the student has difficulty in understanding the principle of the vernier, let him practice reading and reasoning as above, using a large model scale and vernier made of wood or of cardboard, the fixed scale divisions being each 1 cm. long and the vernier scale divisions being each .9 cm. (9 mm.) long.

Note that the *first line* on the vernier is *zero.*

Data. — Tabulate the results.

Zero Error. — Be sure to note the zero error (if there is one) when the jaws are placed together, and make the necessary correction for it.

PART C

BY SUBMERSION IN A GRADUATE

Apparatus. — A graduated glass cylinder and some water are used.

Operations. — The volume of the metal cylinder is to be determined by submerging it in the graduate and finding how many cubic centimeters of water it displaces.

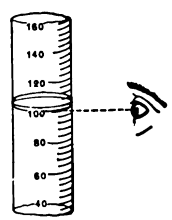

FIG. 3. — Showing the position of the eye when taking a reading.

(*a*) Hold the graduate by the upper end between the thumb and forefinger, allowing it to swing freely, so that it hangs with the axis vertical. Fill it with water up to any convenient division mark; and, holding it so that this mark shall be on a level with the eye, read the position of the bottom of the curved surface, or meniscus, estimating to the tenth of a division. The single divisions may denote cubic centimeters in some graduates, or in others two cubic centimeters each.

(*b*) Incline the graduate, and let the cylinder slide gently to the bottom. Carefully avoid splashing.

(*c*) Take the new reading in the same manner as before. The difference of the two readings represents the volume of the cylinder.

Data. — Tabulate results as below: —

Sources of Error. — Errors arise from (*a*) parallax, (*b*) personal equation, (*c*) any lack of correctness of the scales.

NUMERICAL DATA

Trials	1. (c.c.)	2. (c.c.)
1st reading		
2nd reading		
Volume		
Mean volume		

NOTE.—The error involved in reading from the bottom of the meniscus instead of from the middle is eliminated by subtraction. It is easier to read accurately from the bottom.

Additional Work. — If it is desired to do additional work, a cube or other regular solid may be measured as in Parts A and B. The volume of an *irregular* solid may be determined as in Part C.

Lessons. — These are similar to those to be derived from Exercise 1. Let the student frame a concise and lucid statement of them.

EXERCISE NUMBER 3

DETERMINATION OF MASS BY WEIGHING

REFERENCES

A 23–25, 92	GE 6	H & W 52, 57–58
C 46–48, 98–100	GP 3–6, 35	L 58
C & C 9, 10, 95	H 15	S 18–23, 176
	W & H 11–14, 56, 62	

Apparatus. — The apparatus consists of a balance and a set of masses, technically called "weights," a

pair of pincers for handling the weights, and the solid used in Exercise 2.

The Equal Arm Balance. Operations. — (*a*) See that the balance and the weights are free from dust.

(*b*) See that all the weights are present. To ascertain this easily, notice whether the sockets in which the larger weights belong are all filled; then see that all of the smaller weights are in order in a tray provided for the purpose and placed near the centre of the table, so that they will not be dropped upon the floor. The fractional denominations in most students' sets are as follows: decigrams, 5, 2, 1, 1; centigrams, 5, 2, 2, 1. Report immediately if the set is incomplete or if the balance is not in perfect condition.

FIG. 4. — Showing a convenient method of supporting a "German hand balance."

(*c*) Adjust the balance to equilibrium by adding fine sand to the lighter pan till the pointer swings to equal distances on opposite sides of the zero position. If too much should be added, remove some.

(*d*) Place the object near the centre of one pan and the weights on the other, the largest in the centre and the others close around it. The weights should be tried in order, beginning with one known to be large enough. If the last weight be *too great*, *replace* it by the next smaller; if *too small*, *add* the next smaller. In this manner, continue with the systematic trial of the weights until the opposite excursions of the pointer are equal.

(*e*) Add up the weights in the pan. Their sum is equal to the mass of the object.

(*f*) Add up the weights remaining and add their sum to the sum of those in the pan. Obviously, if the result is the total number of grams in the set, it is known that no mistake has been made in the count, and that no pieces have been lost.

(*g*) Remove the object to the other pan and weigh as before. Take the mean of the two weights thus obtained and record it as the mass of the object.

(*h*) When done with the weighing, see that both scales and weights are in perfect order, return the weights and pincers to their proper places. *These directions are to be followed in all subsequent weighings unless it be otherwise ordered.*

Precautions. — (*a*) The weights and scales must be kept free from dust and liquids.

(*b*) The weights must be handled *with pincers only.*

(*c*) The balances should not be permitted to vibrate while object or weights are being placed in the pans.

These directions apply to balances that have no

adjusting screw and no beam and pan arrests. If the balances are provided with beam and pan arrests, the levers that work these should be lifted each time before adding or removing object or weights, so as to prevent swinging during these operations. If there are no arrests, the pan may be held in the hand while the load is being changed. If there is a screw for adjusting to equilibrium, this is turned toward the lighter side, instead of adding sand. Hand balances can be conveniently suspended upon a vertical support rod by means of a screw clamp. The pans should not be far above the surface of the table.

The Trip Scales. Operations. — (*a*) Place the slider at zero.

(*b*) See that the ends of the knife-edge do not rub against the ends of the bearings. If they do so, the

FIG. 5. — The Trip Scales.

beam will not oscillate freely, but will come to rest rather suddenly. Move the beam very slightly forward or backward till there is no friction.

(*c*) In front of the pointer are two little nuts. Turn the right-hand nut toward you, so that the two

nuts are unlocked; then turn both nuts toward the lighter pan till the balance is adjusted. Lock the nuts in place by turning them toward each other.

(*d*) Weigh as with the equal-arm balance to within 5 grams; then move the slider.

(*e*) The scale reads grams and tenths up to 5 grams; this reading is to be added to the sum of the weights if they are on the right-hand pan, and subtracted if they are on the left. (Why?)

Data. — Tabulate the results as below.

Sources of Error. — State what errors may arise from (*a*) parallax, (*b*) personal equation, (*c*) friction, (*d*) inaccuracy of weights, (*e*) inequality of the arms of the balance. (*f*) Which is eliminated by double weighing?

Numerical Data

Substance	
Form	
Number	
Weight on right pan	g.
Weight on left pan	g.
Mean weight	g.

Lesson. — State in your own words what you have learned. This, the usual method of measuring mass, is based upon the principle that, at a given place, the mass of a body is strictly proportional to its weight. In Exercise 4 the student will learn that masses may be compared without reference to the earth's attraction.

Supplementary to Exercises 2 and 3

DENSITY

References

A 155	GE 6, 114	L 32
C 49	GP 147, 148	S 177
C & C 140, 141	H 145	W & H 15
	H & W 59	

Purpose. — The purpose of this exercise is to calculate the density of the regular solid of exercises 2 and 3.

Definition. — The density of a substance is its mass per unit volume.

If D represent the density of any body, M its mass in grams, and V its volume in cubic centimeters, it follows from the definition that $D = \frac{M}{V}$ grams per cubic centimeter.

Numerical Data

Volume from Ex. 2, Part A	
Volume from Ex. 2, Part B	
Volume from Ex. 2, Part C	
Mean volume from Ex. 2	
Mass from Ex. 3	
Mean density	
Name of substance	

Calculation. — From Exercises 2 and 3, take the data called for in the accompanying tabular form, enter them, and calculate the density by dividing the mass by the volume.

nuts are unlocked; then turn both nuts toward the lighter pan till the balance is adjusted. Lock the nuts in place by turning them toward each other.

(*d*) Weigh as with the equal-arm balance to within 5 grams; then move the slider.

(*e*) The scale reads grams and tenths up to 5 grams; this reading is to be added to the sum of the weights if they are on the right-hand pan, and subtracted if they are on the left. (Why?)

Data. — Tabulate the results as below.

NUMERICAL DATA

Substance	
Form	
Number	
Weight on right pan	g.
Weight on left pan	g.
Mean weight	g.

Sources of Error. — State what errors may arise from (*a*) parallax, (*b*) personal equation, (*c*) friction, (*d*) inaccuracy of weights, (*e*) inequality of the arms of the balance. (*f*) Which is eliminated by double weighing?

Lesson. — State in your own words what you have learned. This, the usual method of measuring mass, is based upon the principle that, at a given place, the mass of a body is strictly proportional to its weight. In Exercise 4 the student will learn that masses may be compared without reference to the earth's attraction.

SUPPLEMENTARY TO EXERCISES 2 AND 3

DENSITY

REFERENCES

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If D represent the density of any body, M its mass in grams, and V its volume in cubic centimeters, it follows from the definition that $D = \frac{M}{V}$ grams per cubic centimeter.

NUMERICAL DATA

Volume from Ex. 2, Part A	
Volume from Ex. 2, Part B	
Volume from Ex. 2, Part C	
Mean volume from Ex. 2	
Mass from Ex. 3	
Mean density	
Name of substance	

Calculation.—From Exercises 2 and 3, take the data called for in the accompanying tabular form, enter them, and calculate the density by dividing the mass by the volume.

CHAPTER II

MECHANICS OF SOLIDS

Exercise Number 4

COMPARISON OF MASSES BY THE ACCELERATION METHOD

References

A 27, 11, 60–66	GP 9–11, 29, 32–38, 41, 44, 63, 78
C 2–7, 14, 16–21, 25–29, 33, 34, 45, 50, 51, 54–56, 58, 63	H 35–40, 44–46
	H & W 62–65, 67
C & C 30–34, 39–44	L 1–12, 29–36, 41–49
GE 10–12, 22, 26, 27, 31–34	S 18–25, 175, 176
W & H 16, 17, 161, 168, 174, 178–183	

Purpose. — The purpose of this exercise is to apply equal forces to two masses for equal time intervals, and to determine whether the greater or smaller mass acquires the greater velocity; to determine whether their masses are equal if with forces equal they receive equal accelerations; and to learn what degree of accuracy is possible in adjusting masses to equality by this method.

Apparatus. — The apparatus is as follows: Two cars, provided with hooks or screws at front and rear; two rubber bands or strips of pure gum tubing, r, r_1, of equal lengths and elastic forces, and with loops at their ends; two smooth boards, B, B_1, with

hooks near their ends; a supply of lead weights or of iron nuts and nails; a spring balance, or a pair of trip scales and weights; a small S-shaped hook of stiff wire.

Operations. — (*a*) By means of the S-hook join the two bands and stretch them over a measuring stick, so that the ends of the bands are at the ends of the stick. If their elastic forces are equal when they are equally stretched, the junction will be at the middle of the rule. Why? If the S-hook does not lie exactly over the middle division, the stronger band must be trimmed along its edge until the hook remains in the right position.

(*b*) Place a load of nails and nuts in one car, and of nails only in the other; attach the rubber bands to the cars and to one of the pairs of hooks in the boards; draw back the cars until the bands are stretched far enough to give the cars *moderate* velocities. Now secure the cars by a piece of twine, looped upon the two hooks in the backs of the cars and passed around the second pair of hooks in the boards.

(*c*) Adjust the cars so that their

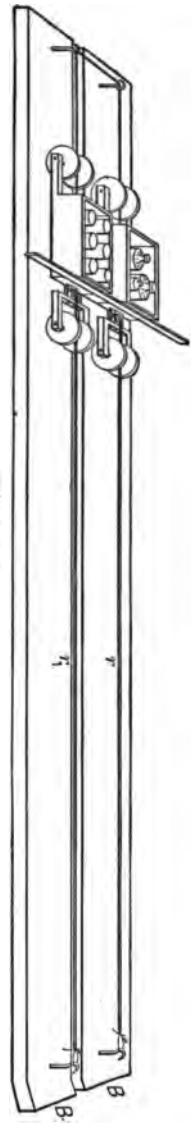

Fig. 6.—Showing cars in position.

front edges are in the same line and the bands equally stretched.

(*d*) Hold a rule between the cars and the two front hooks, and parallel with the line of the front edges of the cars, so that the car boxes, but not the wheels, will strike the rule about where the rubber bands cease to pull.

(*e*) With shears or a sharp knife, cut the twine between the two rear hooks, in order to release both cars at the same instant.

(*f*) Note which car has the greater mass as indicated by the velocity which the tension of the rubber band imparts to it, and, by repeated trials, adjust the masses till the cars have equal velocities, which will be when they start and arrive at the same instant. The adjustment should be made by adding, say, eight nails at a time to the car of lesser mass. When the addition of eight nails causes this car to arrive later than the other, remove as many as necessary of this last eight, — one or two at a time.

(*g*) Test the accuracy of the adjustment by determining the least number of nails which must be added, first to one load and then to the other, in order to cause a *clearly perceptible* difference in the time of arrival.

(*h*) When the adjustment is completed, determine the mass of each car and its load by the method of weighing, with the trip scales, or in a pail suspended on the hook of the spring balance, estimating the fractions of scale divisions in tenths.

(*i*) If time permits, repeat with different masses.

Observations. — (*a*) When the forces are equal and the masses evidently unequal, which mass is given the greater velocity?

(*b*) What is the effect, upon the velocity, of increasing the mass?

(*c*) What is the effect, upon the velocity, of increasing the force? (This can be done by stretching the band farther.)

Data. — Let m = mass of first car and load, m' the mass of the second car and load, R and R' the first and second readings of the balance, P the mass of the pail (to be subtracted from R and R' to obtain m and m'), and n the least amount of additional matter (grams) required to cause an observable change in velocity. If a trip balance is used, the pail will not be needed, and then m and m' are obtained directly. The only quantities to be tabulated will be m, m', and n.

NUMERICAL DATA

TRIALS	R	R'	P	$R-P=m$	$R'-P=m'$	n
1						
2						
3						

Calculate and record your per cent error.

Theory. — Let v and v' be the velocities of the cars, t and t' the time intervals during which they travel,

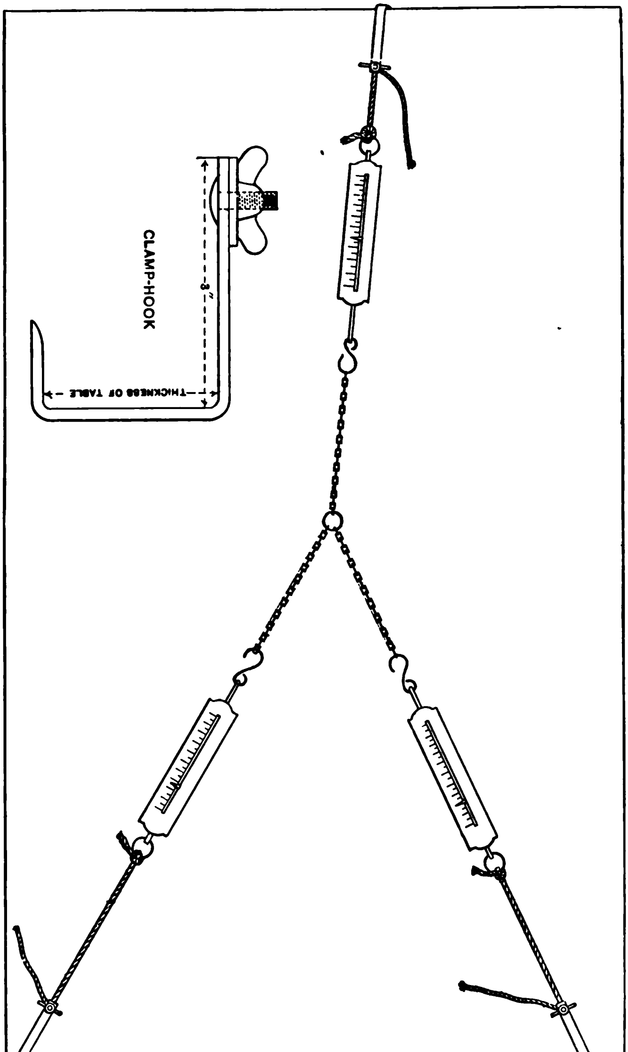

Fig. 7.—Apparatus arranged for experimenting with concurrent forces.

cords are secured at any desired points at the edges of the table by clamp hooks provided with thumb nuts.

Operations. — (*a*) Let each of three students pull steadily on a balance and secure it to a clamp hook. Let the pulls be made at random, in any convenient directions and with any convenient forces, but so that equilibrium shall result.

(*b*) A note-book page is to be slipped under the chains by a fourth student, who, when the equilibrium is secured, marks on the page the positions of the chains. This he does by thrusting a pin through the links, exactly in the middle line of the chain, and pricking two points 1 1, 2 2, 3 3, for each line. The points should be as far apart as possible. *Each line is to be marked with a letter*, which will represent the force in the tabular form.

(*c*) At the same time the other three students record the readings of their respective balances.

(*d*) The positions of the corresponding lines of direction being fixed, and the lines drawn meeting at a point, record the magnitudes of the forces on their respective lines, *remembering to add the proper zero correction for each balance.*

(*e*) Let each student in turn get at least one such set of lines in his note-book; and using these lines, construct the parallelogram of the forces so recorded.

Employing any convenient scale, cut off each line proportional in length to the magnitude of the force it is to represent.

Taking any two of these lines as adjacent sides,

complete a parallelogram, and draw the diagonal from the meeting point of the three lines (point of application) to the opposite vertex. The chosen scale must be small enough so that the whole diagram will go on the page.

(*f*) Measure this diagonal to find the numerical value of the resultant force, record its value, and compare it, both as to direction and as to magnitude, with that of the third of the three forces (the equilibrant).

Zero Correction. — When used horizontally, a spring balance graduated to be used in a vertical position gives a small negative reading under no load. (Why?) This is called the zero error and its amount must be obtained as follows: Hold the balance in the vertical position, and slowly change it to the horizontal, lightly tapping it the while. (Why?)

Take off on a pair of dividers, or a straight-edged bit of paper, the length of the zero error; and apply it to the scale of the balance so as to measure its amount in scale units and tenths. Since all horizontal readings of the balance will be smaller than they ought to be by just this amount, each reading must be corrected by adding to it the amount of the zero error. The readings thus corrected give the real values of the forces observed.

Data. — Record (*a*) the scale of the diagram; (*b*) the values of all four forces (corrected balance readings in pounds and tenths, or in grams); (*c*) lengths of all four lines which represent the

forces; (*d*) name the lines representing both components, the resultant and the equilibrant, and *show their directions by arrow tips;* (*e*) record the amount and per cent of the experimental error, *i.e.* the difference between the numerical values of the equilibrant and of the resultant.

Place the data near the diagram in tabular form, as below.

SCALE OF THE DIAGRAM . . . .

NUMERICAL DATA

NAME OF FORCE	FORCE (LETTERS)	BALANCE READING	ZERO CORRECTION	FORCE AMOUNT IN LBS. OR G.	LENGTH OF LINE
Component					
Component					
Equilibrant					
Resultant					
Experimental error					
Per cent error					

Sources of Error. — Errors may arise from (*a*) parallax; (*b*) friction of the balances, chains, or cords; (*c*) inaccuracies in construction and measurement. Friction may be avoided by lightly tap-

ping the balances and cords to allow them to come into position in straight lines.

In constructing the parallelogram, see that the pencil is kept sharp and the dividers in good condition. Use the utmost care. If all the work is carefully done, the per cent of error will be small. To compute the *per cent* of error, multiply the error by 100 and divide by the value of the equilibrant, which may be taken as the *base*. A given error will be less important in proportion as the *base* is large. Hence use forces as large as practicable.

Inferences. — Answer, in concise sentences, the following questions: (*a*) Neglecting the experimental error, how does the resultant, as found in the experiment, compare in magnitude with the equilibrant?

(*b*) What is the direction of the resultant with reference to that of the equilibrant?

(*c*) Do you, therefore, conclude that the quantity determined in your experiment, and recorded as the resultant of the two forces that were chosen as components, is the true value of their resultant? Copy and memorize the Principle of the Parallelogram of Forces as stated below.

Principle Verified. — If two forces, acting at an angle upon the same point, be represented in direction and magnitude by two lines drawn to any given scale, then the resultant of these two forces will be completely represented, on the same scale, by the concurrent diagonal of the parallelogram constructed upon those two lines as adjacent sides.

In bridges, frames of buildings, and machinery, the

composition and resolution of forces have countless applications. Engineers calculate these forces accurately, so as to use materials sufficiently strong, and yet avoid excessive amounts and the consequent weight and expense. Pick out resultants, components, and equilibrants in structures, machinery, sailboats, kites, etc. Look for tensions and pressures caused by weights and tenacities of parts, winds, "snow-loads," "struts," "ties," etc.

Exercise Number 6

PARALLEL FORCES AND THE LAW OF MOMENTS

References

A 69, 128–132, 134, 135	H 96–105
C 60, 63, 74–77	H & W 84, 85, 99
C & C 47, 93–97	L 53, 107-109, 113–117, 127, 137
GE 45–49, 81–83	S 164
GP 19, 46–49, 84–85	W & H 49–54

Purpose. — In this exercise it is proposed (*a*) to investigate the laws of equilibrium for three parallel forces, and (*b*) to formulate a rule for determining the point of application, direction, and magnitude of the resultant of any given pair of parallel forces.

Apparatus. — AB is half a meter stick, with wire nails driven through it at regular intervals along its axis, at right angles to its faces, and projecting about a half centimeter above and below; *c*, *c*, *c* are pieces of stiff wire, bent into the form of clevises. Three spring balances, with cords and clamp hooks, are used to measure the forces, F_1, F_2, F_3, in a manner similar

to that of Exercise 5. The bar is suspended by a wire, as shown, so that it hangs horizontally about a centimeter above the table.

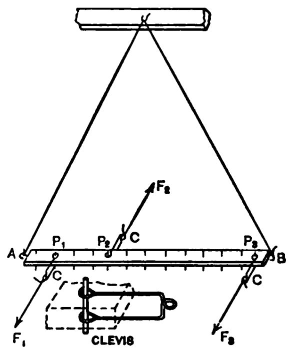

FIG. 8. — Showing how the forces are applied to the suspended bar.

Operations. — (*a*) Arrange the balances so as to exert parallel forces as indicated in the diagram. At least four cases are to be made, by varying the relative distances between the point of application, p_2, of the middle force and the points of application, p_1 and p_3, of the two end forces. These distances are varied by placing the clevises over different nails on the bar and moving the clamp hooks along the ends of the tables.

The forces may be varied in amount by drawing the cords forward or backward at the clamps and securing them by the thumb nuts when the desired tension is attained.

(*b*) Choose any convenient ratios for the distances p_1p_2 and p_2p_3, *e.g.* Case I, $\frac{1}{1}$; Case II, $\frac{1}{2}$; Case III, $\frac{1}{3}$ or $\frac{2}{3}$; Case IV, $\frac{1}{4}$ or $\frac{3}{4}$.

(*c*) *Use the utmost care* to avoid *friction* in the balances or cords, to have the forces act all *parallel* and in the *same plane*, and to see that the bar is in a horizontal position just clear of the table. Be sure that the plane of the wire that supports the weight of the bar is *exactly vertical.*

Data. — (*a*) For each case make a diagram. Represent distances and forces each on a scale appropriate to the size of the page, *e.g.* for distances, 1 cm. = 5 cm.; for forces, 1 cm. = 2 lbs., or 1 cm. = 100 g. Do not crowd more than two cases on a page.

(*b*) Above each diagram state the scale to which it is drawn.

(*c*) Underneath each diagram state what point is adopted as the centre of moments; *choose a different point* for each case, but be sure to use *that point only* throughout *that* case.

(*d*) On the line representing each force, record its value in pounds and tenths, or in grams (corrected for zero error); also *indicate its direction* by an arrow point.

(*e*) Near the line representing each arm, record its length in centimeters.

NUMERICAL DATA

FORCE (LETTER)	BALANCE READING	ZERO CORRECTION	FORCE (AMOUNT)	ARM	MOMENT
F_1					
F_2					
F_3					
		Sum		Sum	

(*f*) For each case fill out a tabular form as above. Be careful to give the dimensions of forces and arms

(lbs., g., or cm.) and the + or − signs of the forces, of the moments, and of the sums. If a force in one direction is called positive, one in the opposite direction is negative; and if a moment acting clockwise is called positive, one acting counter-clockwise is negative.

The sums are understood to be the *algebraic* sums.

Calculations. — Moment = force × arm. If the arm of any force = 0 (*i.e.* if the centre of moments is identical with the point of application of the force), the moment becomes 0. It should, however, be set down in its proper place. In solving the equation, *form the habit* of considering the moment of *each force in turn* from the left to right, *not omitting any.*

Sources of Error. — State briefly the sources of error pertaining to the different parts of the apparatus, and the operations and measurements, also the precautions necessary in order to minimize them.

Inferences. — Frame a concise statement in answer to each of the following questions: (*a*) In order that three parallel forces in the same plane may be in equilibrium, what must be the numerical value of the algebraic sum of the forces, and also of the algebraic sum of the moments about any chosen point?

(*b*) If your results show small + or − quantities for the sums of the forces or of the moments, do you think they may fairly be regarded as due to experimental errors? Why?

(*c*) Which of the conditions mentioned in (*a*) must be satisfied in order to prevent translatory motion? and which to prevent rotary motion?

(*d*) In each case, which force is the equilibrant of the other two, and how must their resultant compare with it in point of application, direction, and magnitude?

(*e*) What, then, is the direction, and what the magnitude of the resultant of any two parallel forces, compared with those of the forces?

(*f*) How does the point of application of the resultant divide the line joining those of the two forces?

Additional Work. — If there is time for extra work, the students may experiment with four or more forces in the same manner as above, or repeat the experiment with the bar not perpendicular to the lines of direction of the forces. In the latter case they should remember to measure the arm of each force on a line *perpendicular to its line of direction.*

Exercise Number 7

CENTRE OF MASS

References

A 94–95	GE 50–53	L 119, 120
C 92–97	GP 52–54	S 161, 162
C & C 52, 54–56	H 74, 75	W & H 57, 58

Purpose. — The purpose of this exercise is to locate the centre of a mass of a pasteboard triangle, and to determine its relation to the medians.

Apparatus. — The apparatus consists of the pasteboard triangle, a pin, and a plumb-line, which may be a heavy button suspended by a thread.

Operations. — (*a*) Pass the pin through the triangle, as near as possible to one vertex, and work it around in the hole till the triangle can oscillate freely about it.

(*b*) Tie the plumb-line to the pin, and drive the latter into the wall. Adjust the thread till it is very near the triangle, but not touching it.

(*c*) Tap the triangle lightly, so that it will oscillate and then come to rest.

(*d*) By means of two fine pencil-marks locate on the triangle the position of the vertical line through the point of suspension, as indicated by the plumb-line.

(*e*) Repeat the operations for the other two vertices of the triangle.

(*f*) Draw the lines on the triangle. If the work has been accurately done, they will meet in a point.

(*g*) Test the accuracy of your work by observing whether you can balance the triangle upon a pin-point at the intersection.

(*h*) Measure and record the distances from the points in which the lines intersect the sides of the triangle to the adjacent vertices.

Data. — (*a*) Choosing a convenient scale, draw a diagram of the triangle, together with the lines mentioned in Operations (*d*) to (*f*).

(*b*) Record, either in tabular form or upon the diagram itself, the measurements of Operation (*h*).

(*c*) Record the scale of the diagram.

Sources of Error. — Make a concise statement, pointing out the sources of error.

Inferences. — Answer in brief, complete sentences, the following questions: —

(*a*) Does each of the lines drawn in Operation (*f*) contain the centre of mass? Why?

(*b*) How is the point determined? Why?

(*c*) Are the lines medians of the triangle? Why?

(*d*) What is the relation of the centre of mass to the centre of figure?

(*e*) Would this be true if the triangle were not of uniform density and thickness?

(*f*) Where is the centre of mass with reference to the thickness of the triangle?

Additional Work. — If there is time for additional work, a *good* illustration of the practical value of this principle is to cut out to scale a pasteboard model of half a stone bridge arch, and by determining the centre of gravity of the model, locate the centre of gravity of the semi-arch.

NOTE. — This exercise may profitably be performed by the students at their homes.

EXERCISE NUMBER 8

WEIGHT OF A BAR. LAW OF MOMENTS

REFERENCES

A 69, 128–132	GE 47, 48, 50, 52, 81	H & W 99
C 60, 63, 74–77, 93–94	GP 49, 52–54	L 120, 127, 137
C & C 55, 93, 94	H 51, 96–105	W & H 59

Purpose. — The purpose of this exercise is to apply weights to a wooden bar, and by calculating their moments about a chosen point, determine the weight

of the bar, *which is to be the unknown quantity in the equation of moments.* (Afterward, the accuracy of the method is to be tested by weighing the bar and comparing the two values thus obtained.)

Apparatus. — (*a*) The bar *ab* is purposely made of irregular shape by fastening to its end a block, or a strap of sheet lead.

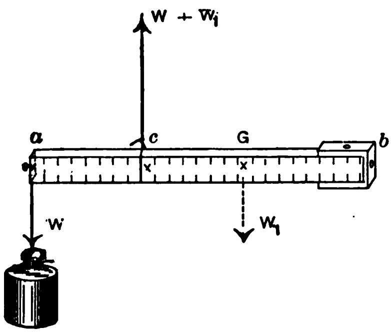

FIG. 9. — Showing how the forces act on the bar.

(*b*) Sliding supports with projecting knife-edges, and a block with bearings, for a fulcrum, are provided; but if desired the bar may be suspended by a slip noose of thread, as shown, instead of using the support and bearings.

(*c*) Pieces of metal are to be used to exert forces.

(*d*) A balance and weights, or a spring balance, is used for weighing.

Operations. — (*a*) Place the bar in the sliding support, which it should fit snugly, and rest the knife-edges of the latter upon their bearings. Move the bar through the support (or thread loop) until it will remain in equilibrium and horizontal. Two forces only are now acting on the bar, — its weight, *W*, a downward force, and the resultant supporting pressure of the bearings (or loop), an upward force. These two forces are in equilibrium ; and their com-

mon point of application is the centre of gravity, G, of the bar, *i.e.* the centre of gravity of the bar is now a little below the line of the knife-edges (or in the vertical plane of the loop of thread).

(*b*) Measure accurately the distance from one end, a, of the bar, to G.

(*c*) Ascertain the weight, W_1, of one of the pieces of metal, and hang it at a. Now balance the bar as before. There are, this time, three forces: W, applied at G, W_1 applied at a, and the upward pressure of the bearings (equal to $W + W_1$) applied at the observed point, which we call c.

(*d*) Measure aG and ac.

(*e*) Diagram the bar and applied forces, with their arms, and near the lines representing these quantities record their values in grams and centimeters. Give *directions* of forces by arrow tips.

(*f*) Write the equation of moments with respect to point a.

(*g*) Make a second case of equilibrium with an additional weight, W_2, suspended at or near the end, b. Now there are four forces. (What are they, and what is the amount of the upward pressure of the fulcrum?) Diagram, record forces, leverages with respect to a, and directions as in the previous cases, and again write the equation of moments.

(*h*) In each of the equations of moments thus written, W is the only unknown quantity.

Solve each equation for W, and average the resulting values. This is the mean value of the weight of the bar as deduced from the data of the experiment.

(*i*) Now weigh the bar and compare the value of *W* thus obtained with the average of the values calculated by applying the principle of moments.

(*k*) If time permits, make up other cases for yourself, and thus become satisfied that *the weight of the bar is one of the forces to be reckoned with* in every case of equilibrium of the bar.

Data. — (*a*) Under the diagram for each case, set forth the numerical data in a neat tabular form similar to that of Exercise 6.

There will be no zero correction, so that two of the columns are not needed.

(*b*) At the end of the record *tabulate all the calculated values of W and their average, together with the value of W obtained by weighing, the difference between the mean calculated value and the value by weighing* (*i.e.* the error), and the *percentage error* (*i.e.* what per cent of the weight *W* this difference is).

Sources of Error. — State them. The most serious ones are likely to occur through inaccuracies in *measuring the distances* on the bar, and as a result of *friction at the bearings.*

Inferences. — Make concise statements in answer to the following questions: (*a*) Can the weight of a body be considered as the resultant of a set of parallel forces? What forces?

(*b*) What name is given to the point of application of this resultant?

(*c*) Is the weight of a beam, rafter, bridge truss, or other piece of structural work a force that should be taken into account in calculating the stress upon it?

Additional Work. — The problem may be repeated with the weight of the bar as a known quantity (determined by weighing) and the distance of the centre of mass from *a* as the unknown, thus locating the centre of mass by calculation; or the weight and this last distance may be determined and the weight W_1 calculated. In each case compare the calculated value of the unknown quantity with the measured value. Look for moments of forces in structures and machinery.

Exercise Number 9

WORK. INCLINED PLANE

References

A 80, 121–127, 140, 141	H 53, 60–62, 94, 111
C 64–66, 69, 71–73, 78	H & W 87, 97, 102
C & C 48, 89–92, 101–103	L 77–80, 93, 137
GE 67, 71–73, 77, 78, 83	S 143–145, 159, 160
GP 62, 70, 74–76, 80, 86	W & H 46, 199–203, 206

Purpose. — The purpose of this exercise is to determine the relation between the amount of work done in moving a body upward along an inclined plane and that done by lifting it vertically through the same difference of level.

Apparatus. — A car, and some iron nuts or other weights, and an inclined plane, are placed as shown. A spring balance is attached to the car by a short stout cord or chain. A metric rule and a pail (or a basket) are also provided.

Operations and Data. — Holding the balance parallel to the plane, and keeping the line of sight perpendicular to the plane of the scale at the point of

reading, move the car up and down the plane, and read the amount of the force indicated while a uniform velocity is maintained. With the usual precautions, take the measurements of the quantities indicated below: —

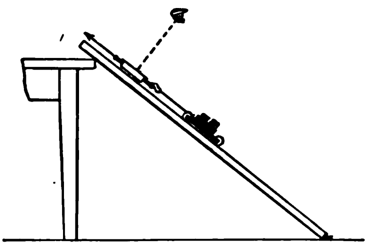

FIG. 10. — Showing how the force is applied and observed.

h, the height of the plane from floor to the point vertically above the table edge.

l, the length of the plane from *floor* to the *same point.*

z, the zero correction for the balance *in position.*

u, force required to maintain *uniform* velocity *up* the plane.

d, force required to maintain *uniform* velocity *down* the plane.

f, $\left(=\frac{u-d}{2}\right)$, the mean force required to balance the *component of weight* of car and load along the plane.

F, $(=f-z)$, the mean force as above, *corrected for zero error.*

$W+p$, the combined weight of the car and its load along with that of the pail in which it is to be weighed.

p, the weight of the pail.

W, $(=[W+p]-p)$, the *combined weight of car and load.*

$F \times l$, the work done *along the displacement*, l, by the force, F.

$W \times h$, the work done in moving the mass against the resistance, W, through the vertical displacement, h.

e, the experimental error.

The values of h and l are to be taken in inches to the nearest $\frac{1}{8}$th, and *reduced to feet and hundredths;* balance readings in *pounds and tenths.* Or if forces are recorded in *grams, the distances* must be in *centimeters;* and if forces are recorded in *kilograms, the distances* must be in *meters.* The amounts of work will then be in foot-pounds, or gram - centimeters, or kilogram-meters respectively. Tabulate as here: —

u		NUMERICAL DATA EXERCISE 9	
d			
f		$W - p$	
z		p	
F		W	
l		h	
$F \times l$		$W \times h$	
e		% error	

Calculations.—The amount of error is the numerical difference between $F \times l$ and $W \times h$. The percentage error is calculated by finding what per cent this difference is of the mean value of the two amounts of work.

Sources of Error. — State the sources of the errors pertaining to (*a*) the length measurements, (*b*) the balance readings, (*c*) the positions of the balances and cord in moving along the incline.

Inferences. — (*a*) Judging by your observations and the experience of the others in the class, do you think it fair to infer that the difference between the corresponding values of $W \times h$ and $F \times l$ are wholly due to experimental errors? (Why?)

(*b*) Make a complete and general but concise statement of the relation existing between the quantities compared.

Exercise Number 10

WORK. INCLINED PLANE (continued)

References

A 141	C & C 101–103	H 111
C 71–73, 78	GP 74–76, 80–86	S 159, 160

Purpose. — The purpose of this exercise is to determine the relation between the amount of work done in moving a body upward along an inclined plane by means of a force applied *parallel to the base of the plane*, and the amount done in lifting the same body vertically through the same difference of level.

Apparatus. — This is the same as that used in the preceding exercise, with the addition of the yoke *y*, which is attached to the front of the car, as shown.

Operations. — Adopt the same mode of procedure as in Exercise 9, except that the balance and cord are to be kept always horizontal.

Great care and some practice will be required in order to do this successfully. A long stout cord attached to the ring of the balance will aid greatly in applying the pull. Let one person pull the cord, while the second steadies the balance as it moves, and a third takes the readings.

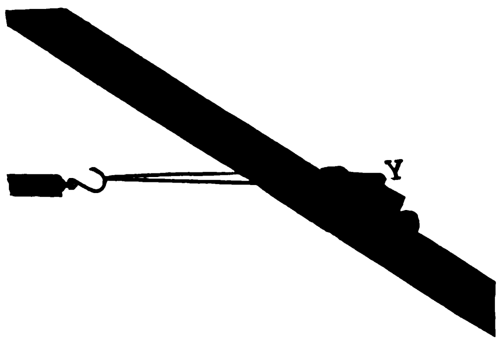

Fig. 11.—Showing how the force is applied parallel to the base of the plane.

Instead of the length of the plane, the *base* is measured from where the inclined plane intersects the plane of the floor to the point where a plumb-line from the table edge meets the floor.

Data.—Tabulate the results precisely as in the preceding exercise, excepting that b (base), P (force parallel to base), and $P \times b$ are recorded in place of l, F, and $F \times l$ respectively.

Sources of Error.—These are similar to the foregoing. Note that the zero correction is to be determined with the balance in the *horizontal* instead of the *inclined* position.

Inferences. — (*a*) Make a complete and general, but concise, statement of the relation investigated.

(*b*) Judging from your own observations and those of your classmates in this and the preceding exercise, do you infer that the amount of work done in *lifting a weight through a given difference of level is dependent or independent* of the length of the path?

(*c*) If the *path* is longer, what about the *amount* of the force required to do the work?

Can this relation be stated mathematically? If so, write the proper expression.

Additional Work. — If it is desired to assign additional work, let new sets of measurements be made, using different inclinations of the plane, and let it be determined whether the proportions $\frac{F}{W} = \frac{h}{l}$ and $\frac{P}{W} = \frac{h}{b}$ always hold true. Note that these proportions may be written $F \times l = W \times h$ and $P \times b = W \times h$. Find examples of work wherever you see bodies moving.

Exercise Number 11

LAWS OF THE PENDULUM

References

A 106, 112–120	GE 60–63	H & W 74–81
C 68, 87–89	GP 65–69	L 73, 141–143
C & C 68–77	H 83–91	S 173, 174
	W & H 189–193	

Part A

EFFECT OF LENGTH AND AMPLITUDE

Purpose. — The purpose of Part A is twofold: (*a*) to learn whether the period of a pendulum is

affected by the amplitude of vibration, and (*b*) to determine whether the period of a given pendulum varies directly as the square root of its length. More briefly, the aim is to verify the laws of the pendulum regarding amplitude and length.

Apparatus.—(*a*) The pendulum is made of a bullet of about 1.5 cm. diameter, into which is moulded a very small wire loop. A silk thread 120 cm. long is attached to this loop at one end, and passed into a knife slit in a cork near the other end.

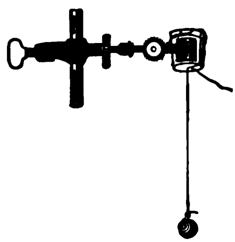

FIG. 12.—Showing how the pendulum is suspended.

(*b*) By means of a screw clamp attached to a vertical rod, the cork is firmly supported so that the thread hangs perpendicular to the face from which it emerges.

(*c*) The meter stick and rectangular block of Exercise 1 and the calipers of Exercise 2 are needed for measuring the lengths and the diameter of the bob.

(*d*) For the time measurements a good timepiece, capable of marking seconds, is needed (*e.g.* a student's watch, a stop-watch, a metronome, or, best of all, a telegraph sounder, electrically connected with a good laboratory clock.

Operations.—(*a*) Carefully measure the diameter of the bob.

(*b*) Loosen the thumb-nut of the clamp, and draw the thread up or down through the slit in the cork, so as to make the pendulum between 25 and 50 cm. long.

(*c*) Tighten the nut (if necessary, give the end of the thread several turns around the cork, passing it again into the slit), so that the thread will not slip.

(*d*) Measure the length of the pendulum as follows: place the end of the meter stick against the under surface of the cork, and so that the thread hangs vertically just in front of the scale. Now, holding the block against the scale with its upper surface horizontal and below the bob, slip it upward carefully till it is just tangent to the bottom of the bob, and read on the scale the distance of this surface from the end of the rule. This is the distance from the bottom of the cork to the bottom of the bob; and the approximate real length of the pendulum is obtained by subtracting from it the *radius* of the bob. (Why?)

(*e*) Record the data in centimeters and hundredths.

(*f*) In order to adjust the rule as above, it may be necessary to slide the clamp to the top of the support, or even to remove it altogether; but after the length is measured it should be readjusted on the rod at such a height that the bob hangs about 2 cm. above the surface of the table. This is the most convenient position for the work that follows.

(*g*) Set the pendulum swinging over a small arc not exceeding 10° of a circumference. Let the length of the arc be roughly determined by a meter stick placed beneath the bob.

(*h*) Place your pencil point near the top of a sheet of paper, but not touching it, and move the pencil

back and forth in unison with the pendulum, keeping the bob always in sight.

(*i*) At the instant when the second hand of the timepiece reaches zero, lower the pencil point so that it touches the paper, and continue the motion in unison with the pendulum, at the same time slowly moving the hand toward the bottom of the sheet, thus making a zigzag line on the paper. Each segment of this broken line represents a single oscillation of the pendulum, and any fraction of a segment represents approximately a corresponding fraction of an oscillation.

(*j*) At the instant when a given number of seconds is completed (say 60 or 100) raise the pencil from the paper.

(*k*) Count the number of segments and tenths of a segment in the zigzag record line. The result is the number of oscillations made by the pendulum during the given number of seconds.

(*l*) It is better to let another student work with you (unless the stop-watch is used). He should say "tick" at the beginning of the time interval agreed upon, and then count (in silence) "one, two," etc., up to (say) fifty-nine (this time aloud); at the sixtieth click of the sounder he again says "tick." If the second's dial can be seen, it should always be watched in order to verify the count. If the stop-watch is used, the student can work better alone, counting one hundred oscillations of the pendulum, the watch being started at the beginning of the interval and stopped at the end of it. In this case,

place a pointer in front of the thread near the bob at its lowest position, and reckoning the time between two successive passages of the pointer *in the same direction* as the time of *two* oscillations. Instead of a stop-watch an ordinary watch may be used. Set the minute and second hands so that they begin the minutes together. *Estimate* fifths of a second.

(*m*) Without altering its length, vibrate the pendulum over a different arc (less than 15°) and determine as before the number of oscillations in a given time.

(*n*) Repeat for a third length of arc (still, less than 15°).

(*o*) Adjust the pendulum to a length between 50 and 75 cm.; determine the real length, and make observations for three different short arcs as before.

(*p*) Make the length from 75 to 100 cm., and repeat all the operations as above.

Data and Calculations. — Tabulate the results as below. Let D be the distance from cork to bottom of bob, R the semi-diameter of the bob, l the real length (equal to $D - R$), a the length of the arc in centimeters, o the whole number of oscillations in the given time, s the number of seconds required to make the number of oscillations o, t the period, or time of one oscillation (equal to the number of times o is contained in s), and k the ratio of the period to the square root of the corresponding length (*i.e.* $\left(\frac{t}{\sqrt{l}}\right)$ for each determination of t. k is to be expressed as a *decimal* fraction.

NUMERICAL DATA

	LENGTH OF ARC a	OSCILLATIONS o	NUMBER OF SECONDS s	PERIOD t	RATIO $k\left(=\frac{t}{\sqrt{l}}\right)$
D					
R					
l					
D					
R					
l					
D					
R					
l					

Sources of Error. — State concisely what errors may pertain to (*a*) the timepiece, (*b*) the observers, (*c*) the measurements of length.

Inferences. — In complete sentences, answer the questions below.

(*a*) Do your values of t corresponding to a given length, differ by amounts too great to be ascribed to the inevitable errors of the experiment?

(*b*) If not, when the length and place remain the

same, is the period dependent upon the length of the arc.*

(*c*) Do you consider it fair to assume that the values of $\frac{t}{\sqrt{l}}$ are all equal, or, in other words, that $\frac{t}{\sqrt{l}}$ is a constant ratio for all lengths?

(*d*) If l and l' be two lengths, and t and t' be the corresponding periods, and if $\frac{t}{\sqrt{l}} = k$ (a constant quantity), and $\frac{t'}{\sqrt{l'}} = k$ also, show that $\frac{t}{t'} = \frac{\sqrt{l}}{\sqrt{l'}}$.

(*e*) If you have answered (*b*) and (*c*) in the affirmative, state the two laws of the pendulum which you have verified by your experiments as far as they go.

Part B

ACCELERATION OF GRAVITY

Purpose. — The purpose of Part B is to calculate the mean value of g at the school laboratory from the data obtained in Part A.

Calculations. — (*a*) Put the equation of the pendulum, $t = \pi\sqrt{\frac{l}{g}}$, into the form $g = \frac{\pi^2 l}{t^2}$.

(*b*) In this formula, substitute 3.1416 for π. Substitute for l the first value of length taken from the tabulated results of Part A. Average the values of the period of oscillation belonging to this length, and

* Half the arc measures the amplitude of the oscillation, and theoretically it should not exceed 5°, but practically it will be difficult in this experiment to make it quite so small.

put the resulting quantity in place of *t*. Solve the equation for *g*.

(*c*) In like manner, substitute and calculate the value of *g* from each of the other lengths and its corresponding mean period.

(*d*) Tabulate and average these values of *g* to find the mean acceleration of gravity at your laboratory.

(*e*) If given the theoretical value of *g* in your latitude by your teacher, find your error by subtraction, and calculate your percentage error. To do this, multiply your error by 100 and divide by the given value of *g*.

PART C

GRAPHIC REPRESENTATION OF THE LAW OF LENGTH AND PERIOD

Purpose. — The purpose is to plot a curve, showing the relation between the lengths of a pendulum and the corresponding periods of oscillation.

Operations. — (*a*) Near the lower left-hand corner of your note-book page, which is ruled in $\frac{1}{2}$ cm. squares, or on engineer's cross-section paper, choose for the origin a point, *O*, at the intersection of any two lines.

(*b*) From *O* draw a vertical line, say 10 cm. long, and mark it, **Axis of Ordinates.** From *O* draw a horizontal line of the same length and mark it, **Axis of Abscissas.**

(*c*) Near the axis of abscissas, write, "Values of *l*. Scale ; 1 cm. = 10 cm.," and, using this scale, mark

points on the axis of abscissas at distances from O equal respectively to the values of l that were used in your experiments. Opposite each of these points place its numerical value (l in cm.) and the number of scale units corresponding.

(*d*) Near the axis of ordinates, write, "Values of t. Scale; 1 cm. = .1 second," and, using this scale, mark points on the axis of ordinates at distances from O equal respectively to the values of t obtained in your experiments. Opposite each of these points place its numerical value in seconds and tenths, and also in terms of the scale.

(*e*) From the point belonging to the smallest value of l, erect a dotted line parallel with the axis of ordinates; and from the point belonging to the corresponding value of t, draw a dotted line parallel to the axis of abscissas. Produce these two lines till they meet in a point. This point is, theoretically, a point in the required curve; and the two dotted lines are its coördinates, — the vertical being its ordinate and the horizontal being its abscissa.

(*f*) Draw the abscissa and ordinate of the point which represents the next value of l and its corresponding value of t, and mark the second point as you marked the first. Continue the process until all the values of l and their corresponding values of t have been plotted and the intersections of their coördinates marked. It is well to draw a little circle round each point.

(*g*) Now sketch lightly a smooth curve through the origin and through the points determined. If it

cannot be made to pass through all the points without sharp bends or turns out of its course, make it follow an average course, taking in the largest number of points that it can be made to pass through without sharp bends.

(*h*) Line in the curve, preferably with red ink, making it of uniform thickness. In drawing the curve, a piece of whalebone or a "French curve" will be of assistance.

Remarks. — If a simple relation exists between the values of one variable and the corresponding values of another variable dependent upon the former, their relation can always be shown graphically by a curve constructed as above. If the curve does not pass through all the points, the variation of the points from the average position of the curve is due to experimental errors, or to some cause for which a correction may be introduced. If the dependent variable changes by equal amounts when the independent variable changes by equal amounts (*i.e.* when the relation is a direct proportion), the "curve" becomes a straight line.

The particular kind of curve obtained in this exercise is known as a parabola, and its mathematical law is expressed by the general equation, $y^2 = ax$, where y is any ordinate, x its corresponding abscissa, and a some constant.

To determine whether the curve, which seems to be a parabola, is really a parabola, plot a new curve in the same manner as above, using the square root of the lengths for the x's (abscissas) and the corresponding values of t for the y's (ordinates). If the resulting curve is a straight line, then it can be shown by the geometry of similar triangles that the x's are directly proportional to the y's, as mentioned above. This proves that the law of the pendulum is

$$\frac{t}{\sqrt{l}} = \frac{t_1}{\sqrt{l_1}} = \frac{t_2}{\sqrt{l_2}} = \text{etc.}$$

Squaring, we have

$$\frac{t^2}{l} = \frac{t_1^2}{l_1} = \frac{t_2^2}{l_2}, \text{ etc.} = a, \text{ some constant.}$$

Therefore if any value of t be represented by y, and its corresponding value of l by x, $\frac{y^2}{x} = a$, $\therefore y^2 = ax$, the law of the parabola, as above. Thus, by the graphic method of examining our numerical data, we have shown that the law of the pendulum is expressed by the law of the parabola. That is, putting it in ordinary language, instead of the language of algebra, the squares of the periods of pendulums at a given place are directly proportional to the corresponding lengths. The constant in the last column of your experimental results is the square root of the constant, a, of the equation $y^2 = ax$.

This exercise shows how the law of the pendulum might have been discovered by the graphic method, had it not been already known to you; and it also illustrates how convenient is the graphic method when employed by skilled mathematicians in examining relations between physical quantities.

Part D

INFLUENCE OF MASS ON PERIOD

Purpose. — The purpose is to find whether a change in the mass of the bob makes any change in the period of oscillation, the length and location being constant.

Apparatus. — This consists of a hollow brass cylinder * which has a bail by which it may be suspended,

* Instead of the bob above described, there may be supplied a small cylindrical tin box, having a screw-top. The wire is passed through a small hole punched in the centre of the top, and is soldered on the under side. The jar is to be filled with sand for the first trial, and with shot for the second. It must be *full* both times.

and into which a solid brass cylinder just fits. The cylinder is suspended by a fine steel wire, a meter or more in length, which is gripped at its upper end in a suitable clamp or a small vise. The timepiece of Part A is used.

Operations. — (*a*) Remove the solid cylinder and observe, as in Part A, the number of oscillations in 100 seconds, or take the time of 100 oscillations, as preferred.

(*b*) Replace the solid cylinder, and repeat the operations.

Data. — Tabulate the values of total time, number of oscillations, and the period deduced therefrom as observed from a series of trials.

Inference. — (*a*) Does the period remain practically constant?

(*b*) Is this what you might have expected from consideration of the fact that the formula $t = \pi\sqrt{\frac{l}{g}}$ contains no expression for mass?

(*c*) State the law which has been verified.

Sources of Error. — In addition to the errors of Part A, the most likely one arises from the stretching of the wire by the additional weight of the solid cylinder. To avoid this, place a little marker so that the bottom of the bob just touches it when the empty cylinder is at rest in its lowest position. After the solid cylinder has been replaced, observe again the position of the bottom of the bob with reference to the marker, and if the wire has stretched, shorten it at the clamp till it is of the same length as before.

CHAPTER III

MECHANICS OF FLUIDS

Exercise Number 12

RELATIVE DENSITY BY THE SUBMERSION METHOD

References

A 153, 155, 156, 160 GE 114–116 H & W 59, 112, 113
C 124 GP 146–149 L 169–176
C & C 134–136, 140–144 H 143, 146–150 S 26–31
W & H 72, 73, 75

Purpose. — The purpose of this exercise is to determine (*a*) the relative density of a solid and (*b*) the relative density of a liquid with reference to water as a standard. The solid chosen is to be denser than water or the liquid, and is to be insoluble in either. Under these conditions the methods are of general application.

Part A

OF A SOLID

Apparatus. — The apparatus provided consists of balance and weights, thread, a jar or beaker of distilled water, and the cylinder used in Exercises 2 and 3. Diagram the apparatus as used.

Operations. — (*a*) Make a slip-noose at one end of the thread and a loop at the other end.

(*b*) Pass the loop over the hook * on the bottom of one of the scale pans, adjusting it to such a length that the solid, when suspended in the noose, will hang 10 or 15 cm. below the pan.

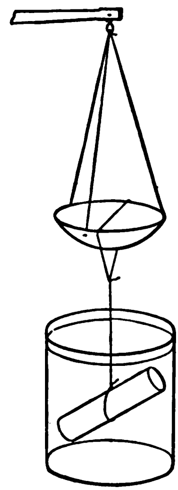

FIG. 13.

(*c*) Adjust the scales to equilibrium with the thread so attached.

(*d*) Suspend the solid, or place it in the pan, and obtain its weight, W.

(*e*) Suspend the solid in the jar of water, adjusting the scales so that it is totally submerged when the beam is horizontal, but touches neither the sides nor bottom of the jar; and obtain the apparent weight, W_1.

(*f*) If time permits, suspend the solid from the other pan, and obtain the values of W and W_1 as before, using their mean values, as in Exercise 3. Ordinarily the arithmetical mean will do, because it does not usually differ from the geometric mean by an amount greater than that of the unavoidable errors of experiment.

* If the balance pans have no hooks, the thread may be suspended, as shown in Fig. 13. If suspended in this way from the trip scales, the scales must be mounted on a box or other support, with the end of the balance projecting over the end of the box. The loop must be long enough so that the thread will not touch the base of the balance or any part of its support. A bit of soft wax will keep the thread in place. If the balances have the perforated horn pans, close the holes with corks and put small screw-hooks into the corks from below.

Data. — Record data in the tabular form below.

NUMERICAL DATA

Substance of the solid		
Form of the solid		
Number of the solid		
Weight,	W	
Apparent weight in water,	W_1	
Buoyant force,	$W - W_1$	
Relative density,	$\frac{W}{W - W_1}$	
Density from Exercises 2 and 3		

PART B

OF A LIQUID

Apparatus. — A jar of the liquid * whose relative density is to be determined is added to the apparatus of Part A.

Operations. — The only additional operation is that of obtaining the apparent weight of the solid while submerged in the liquid under examination.

Data. — Tabulate these as below, using the values of W and W_1 obtained in Part A.

* *E.g.* a saturated solution of common salt or of copper sulphate. Iron and lead cannot be used in the latter liquid, as it acts upon them chemically.

NUMERICAL DATA

Substance of the solid		
Form of the solid		
Number of the solid		
Weight,	W	
Apparent weight in water,	W_1	
Buoyant force of water on solid,	$W - W_1$	
Apparent weight in liquid,	W_2	
Buoyant force of liquid on solid,	$W - W_2$	
Relative density of liquid,	$\frac{W - W_2}{W - W_1}$	
Name of liquid		

Sources of Error. — These are as follows: (*a*) Imperfections of the balances and weights.

(*b*) Parallax in observing the pointer of the scales.

(*c*) Friction of the liquid on solid and thread, reducing the sensitiveness of the balance.

(*d*) Buoyant forces of the liquids on the thread. In very accurate work a silver or platinum wire is used, and corrections are made for the buoyant forces on it.

(*e*) Buoyant force of air on the solid. When great accuracy is sought, the corrections for deducing the weights in a vacuum are applied.

(*f*) Water may not be pure and at 4° C. Corrections for temperature can be applied.

Inferences. — (*a*) If, by definition,

$$\text{specific gravity} = \frac{\text{weight of the body}}{\text{weight of an equal volume of water}},$$

can the numerical value of this ratio be obtained by taking the numerical value of the expression

$$\frac{\text{weight of the body}}{\text{buoyant force of water on the body}}? \quad \text{Why?}$$

(*b*) If, by definition, specific gravity of a liquid

$$= \frac{\text{weight of a given volume of the liquid}}{\text{weight of the same volume of water}},$$

can the numerical value of this ratio be obtained by taking the numerical value of the expression

$$\frac{\text{buoyant force of the liquid on a solid}}{\text{buoyant force of water on the same solid}}? \quad \text{Why?}$$

(*c*) Is the numerical value of the relative density the same as that of the specific gravity? Why?

The density of a substance is one of its most important characteristics. The knowledge of it is often indispensable, not only to the scientist, but also to the manufacturer, merchant, and consumer. Find some instances.

Exercise Number 13

RELATIVE DENSITY BY THE FLOTATION METHOD

References

A 154, 157, 160	GP 150	L 172, 174, 177
C & C 138–144	H 144, 150	S 31
GE 117	H & W 113	W & H 74, 75

Purpose. — In this exercise it is proposed (*a*) to determine the relative density of a wooden rod by applying the principle of flotation, and (*b*) to determine the relative density of a liquid by using the rod as a constant weight by hydrometer.

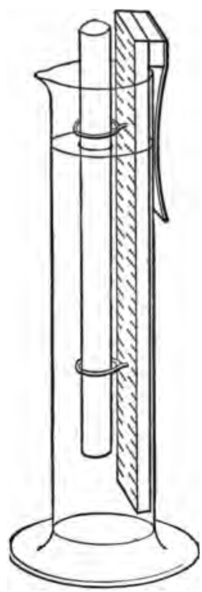

Fig. 14. — Showing the rod and support in position.

Apparatus. — (*a*) The rod of wood whose relative density is to be found must be of uniform cross-section, and should be given a thin coating of paraffin, so that it cannot absorb the water or other liquid.

(*b*) A supply of distilled water and of the liquid, each in a tall glass jar.

(*c*) A support for floating the rod upright consists of a piece of a meter rule, with two screw-eyes set horizontally into the front of it. A spring clamp attached to the back of it holds it firmly against the side of the jar.

Part A

OF A SOLID

Operations. — (*a*) Place the support vertically in the jar of water, and see that the clamp holds it firmly in position.

(*b*) Pass the rod vertically downward through both screw-eyes, and carefully allow it to sink just as far as it will. Tap very gently on the side of the jar, or support, in order to overcome any friction that may interfere with free motion of the rod upward or downward.

(*c*) Take two readings, on the support, of the position of the lower end of the rod, and the same number of readings of the upper level of the water. Wipe the rod dry, reverse it and repeat, taking four readings as before. Take the mean of the four readings for the lower end, and also the mean of the four readings for the water level. Avoid parallax by keeping the eye on a level with the point at which the reading is taken. If the surface of the water is elevated by capillary action near the rod, give the rod a fresh coat of paraffin.

(*d*) With a metric rule take four measurements of the total length of the rod.

Data. — Enter the data in a tabular form like that below. The length of the part submerged is obtained by taking the difference between the mean upper and mean lower readings. The relative density of the wood is calculated by dividing the length of the part submerged by the length of the entire rod.

NUMERICAL DATA

	Reading Lower End	Reading Water Surface	Length of Submerged Part	Length of Entire Rod
1				
2				
3				
4				
Mean				
Name of substance				
Relative density				

Theory. — Let $W =$ weight of rod, m its mass, l its length, and V its volume; let $W' =$ weight of water displaced by submerged part, m' its mass, v' its volume, l' its length (*i.e.* the length of the submerged part of the rod); and let D be the density of the substance of the rod, D' the density of water, and a the cross-sectional area of the rod.

Then $W = W'$ (Principle of Flotation); and since $W = m$, and $W' = m'$ (mass is numerically equal to weight),

$$m = m'. \qquad \text{(Why ?)}$$

Also $\qquad m = VD$ and $m' = V'D'$;

$\therefore\ VD = V'D'.$ (Why?)

But $\qquad V = al$ and $V' = al'$. (Geometry.)

Whence, by substitution,

$$alD = al'D';$$

and dividing by alD',

$$\text{Relative Density} = \frac{D}{D'} = \frac{l'}{l}.$$

Evidently this method applies to any substance less dense than water, provided it be cut of uniform cross-section, with its bases approximately perpendicular to its length.

Part B

OF A LIQUID

Operations. — (*a*) Wipe the rod and support (Why?), and repeat operations (*a*), (*b*), and (*c*) of Part A, but with the rod floated in the liquid whose relative density is to be determined instead of in water.

In a tabular form like that on the following page enter the data thus obtained, together with the necessary datum from Part A.

(*b*) Calculate the relative density by *dividing the mean length of the part submerged in water* by the mean length of the *part submerged in the liquid*, in accordance with the theoretical deduction above.

NUMERICAL DATA

TRIAL	READING LOWER END	READING LIQUID LEVEL	LENGTH OF PART SUBMERGED
1			
2			
3			
4			
Mean			
Length of part submerged in water			
Relative density of liquid			
Name of liquid			

Theory. — Let W, M, V, a, and l represent, respectively, the weight, mass, volume, sectional area, and length of the displaced liquid; and let W', M', V', a, and l' represent, respectively, the same quantities for the displaced water. Also let D and D' be the densities of the liquid and of water.

Then $W = W'$ (since by the Principle of Flotation each is equal to the weight of the rod); and by reasoning precisely similar to that of Part A,

$$\frac{D}{D'} = \frac{l'}{l} = \text{Relative Density of the Liquid.}$$

Sources of Error. — Errors result from (*a*) parallax, and errors of judgment in reading (personal equation). (*b*) The rod and support may not be exactly vertical. (*c*) Slight friction may prevent the rod from floating freely. (*d*) The rod may not be exactly vertical.

Lessons. — This exercise gives valuable practice in manipulation, and in the application of the principle of flotation for the rapid determination of density where refined methods are not available. It also illustrates the principle which underlies all constant weight hydrometers.

The principle of flotation is fundamental in ship designing. The weight of a vessel equals its "displacement." A battleship designed to carry heavy armour and heavy guns must have a large displacement and great stability. This necessitates increased draught and breadth of beam. The naval designer must compromise between weight and speed. Compare a protected cruiser with a first-class battleship.

Additional Work. — Other woods and other liquids may be given, if desired.

Note. — If the support is not at hand, the rod may be supported laterally by the finger tips. A ring of fine silk thread may be adjusted on the rod to mark the upper level of the liquid, and the length of the part that was submerged measured by a rule. Paraffining the rod and support serves the additional purpose of preventing the liquid from adhering to them, and thus disturbing the true level of the liquid. It is desirable to use the same liquid that was chosen for Exercise 12, so that the results by the two methods may be compared, and a check on their accuracy thus secured.

Exercise Number 14

RELATIVE DENSITY OF A LIQUID BY HARE'S METHOD

References

A 165, 166	GP 131, 144, 149	S 48, 62
C 131–133	H pg. 139, 159–161	W & H 77
C & C 146–148	H & W 121, 153	
GE 102–104	L 182	

Purpose. — The purpose of this exercise is to determine the relative density of a liquid by the method of balancing columns supported by atmospheric pressure.

Apparatus. — The apparatus consists of two glass tubes, each nearly a meter long, and joined by rubber tubing to the two branches of a three-way tube (made from a T-tube bent as shown); and to it is attached a long rubber tube terminating in a glass mouthpiece. The glass tubes are secured to a meter stick by rubber bands, and the meter stick is fastened in a vertical position by screw clamps (or by any convenient support). Its end rests on the table-top. The ends of the glass tubes should terminate in short rubber tubes which dip into two beakers or small jars, one containing distilled water, and the other the liquid whose relative density is to be determined.*

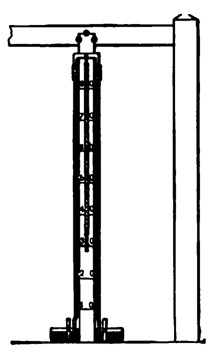

Fig. 15. — Apparatus for the determination of relative density by Hare's method.

* Use the same liquid as in Exercises 12 and 13.

F

A pinch-cock, or a Hoffman screw-compressor, is placed above the mouthpiece on the rubber tube, to prevent the ingress of air after it has been withdrawn.

Operations. — (*a*) Remove, rinse, and replace the mouthpiece.

(*b*) Open the pinch-cock, remove air from the tubes until the columns of liquid stand a little below their upper ends.

(Why do the liquids rise to unequal heights? Which liquid is the denser?) The air is to be removed by suction at the mouthpiece a little at a time, so as never to allow the liquids to be pushed over the bend. (Why?) In case such an accident should occur, remove the entire apparatus to the sink and rinse it thoroughly. The columns can be held at any desired point, while the pinch-cock is being adjusted, by closing the end of the mouthpiece *with the tongue.*

(*c*) After closing the pinch-cock, watch the apparatus for a moment, to see that it does not leak, then read on the rule the positions of the upper ends of the columns. Read to tenths of millimeters, being careful to avoid parallax. In like manner read the position of the liquid surface in each of the beakers. Make each upper and each lower reading from the bottom of the meniscus. In reading, it is convenient to hold a straight-edged card against the scale and tube, with its upper edge parallel to the divisions of the rule. The two lower readings should be taken as nearly as possible at the same instant, and so also should the two upper readings.

(*d*) Let the liquid columns run down a few centimeters, and repeat the observations. Take as many sets of readings as time permits. Remember that

the longer the columns, the less is the percentage error. In order to eliminate the small error due to capillary action, it is well to have a short piece of tubing, like that of the apparatus, placed in each beaker, and to take each lower reading at the bottom of the meniscus in the short tube. This tube should be held vertically, and not too near the long tube or to the side of the beaker.

(*e*) Remove the pinch-cock after completing the readings.

Data and Calculations. — Record the *name* of the liquid, the readings, and the derived data in a tabular form like that below. The height of each column is obtained by subtracting the smaller reading from the greater. The relative density for each set of readings is obtained by *dividing the height of the water column* by the height of the *liquid column.* Compute the mean relative density from the numbers in the last column, and record it below the data, together with the values of the relative density of the same liquid obtained in Exercises 12 and 13.

NUMERICAL DATA

Water			Liquid			
Lower Reading	Upper Reading	Height of Column	Lower Reading	Upper Reading	Height of Column	Relative Density

Theory. — Let m, v, a, h, and D represent respectively the mass, volume, sectional area, and height of the liquid column; and let m', v', a, h', and D' represent the same quantities for the water column.

Then since they are balanced by the same resultant atmospheric pressure, the weights and therefore the masses of the two columns are equal, *i.e.* $m = m'$.

But $$m = vD = ahD$$

and $$m' = v'D' = ah'D'. \qquad \text{(Why ?)}$$

$$\therefore\ ahD = ah'D'; \qquad \text{(Why ?)}$$

and $$hD = h'D'. \qquad \text{(Why ?)}$$

Whence $$\frac{D}{D'} = \frac{h'}{h} = \text{Relative Density.} \qquad \text{(Why ?)}$$

Sources of Error. — (*a*) Errors may arise from temperature changes. In very accurate work corrections must be applied for expansion; or the columns must be cooled to 4° C.

(*b*) Dirt in the tubes may affect the amount of capillary elevation or depression.

(*c*) There will also be errors due to parallax and personal equation.

Lesson. — Besides useful laboratory practice this exercise affords valuable practice in applying the principles of fluid equilibrium.

Barometer

Reading the Barometer. — (*a*) Turn the screw *O* to the left until the mercury in the cistern is seen to withdraw below the little ivory point at *B*. This ivory point represents the zero end of the scale that is attached to the metal case.

(*b*) Looking so that the line of sight is tangent to the mercury in the cistern, slowly turn the screw *O* to the right until the ivory point *just meets* its image reflected in the mercury.

(*c*) By turning the screw *D* from you, raise the lower edge of the sliding (or vernier) scale, *C*, until you can see over the upper surface of the mercury column.

(*d*) Place the eye on a level with the highest point of the mercury column, and by reversing the screw *D* lower the vernier till its zero line appears just tangent to the curved surface of the mercury.

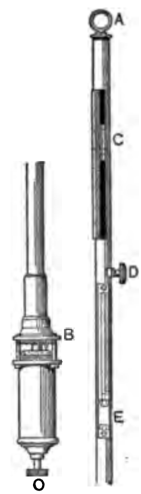

Fig. 16.—U. S. Weather Bureau Standard Station Barometer.

(*e*) Read the scale and vernier precisely as directed for the vernier slide caliper, Exercise 2, Part B.

(*f*) If the barometer reading is to be taken in inches instead of in centimeters, note that inches and tenths are measured by the fixed scale and hundredths of inches by the vernier.

Correction for Temperature. — The temperature of the room being higher than 0° C., the mercury column and the scale by which it is measured are both expanded by the heat, and therefore are longer than they would be at 0°. As the readings of air pressure are customarily based upon the supposition that the temperature of the mercury is zero, it is usual to observe the temperature of the barometer by means of the "attached thermometer" (*E*, Fig. 16), and to correct the observed height of the column for the error due to expansion. The correction is the difference between the expansion of the mercury column and that of the brass scale by which it is measured. (Would a correction be necessary if both expanded equally?) Since the temperature of the room is *above* zero, and since the mercury expands *more* than does the brass, the observed height is too great, and the correction is to be subtracted. The amount of the correction is jointly proportional to the length and to the temperature of the mercury column.

The corrections for all pressures and temperatures have been calculated, and are published in the tables of the United States Weather Bureau. Unfortunately, the pressures are expressed in inches and the temperatures in Fahrenheit degrees. So that the barometer should be read accordingly, if its indication is to be thus corrected.

To find the correction for temperature, consult the *Table for Reduction to* 32° *F.*, in accordance with the rule given below.

In the vertical column at the left find the temperature that was observed on the attached thermometer. Follow the line of this number to the right till you reach a column of figures, headed by the pressure-reading that you observed. In this vertical column, the number directly opposite your attached thermometer-reading is the correction required. If the exact temperature and pressure that you observed are not shown in the table, select the nearest values that are tabulated.

Other Corrections. — When readings simultaneous *at different places* are to be compared, they are all reduced to what they would be at sea level. The capillary depression of the mercury in the tube is corrected by permanently lowering the scale.

Exercise Number 15

BOYLE'S LAW

Part A. — Verification

References

A 168, 169	GP 131, 137	S 63–65
C 136–142	H 166–168	W & H 79–81
C & C 161–163	H & W 124, 125	
GE 107	L 189–190	

Purpose. — The purpose of this exercise is to determine the relation between the volume of a given mass of gas, at constant temperature, and the pressure under which it is confined; or, more briefly, it is to verify the law of Boyle.

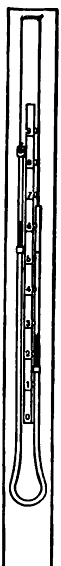

Fig. 17. — Apparatus for verifying Boyle's Law.

Apparatus. — (*a*) A glass tube about 30 cm. long, closed at one end by a capping disk and clamp screw, is joined by about a meter of rubber gas tubing to another glass tube of the same bore, open at both ends and about 50 cm. long. This composite tube is mounted on a board so that the two sections of glass tubing are vertical, and can slide up and down on opposite sides of a meter rule. They are suspended by a cord, sliding over screw hooks at the top of the board, and can be held in position by stiff rubber bands. The apparatus contains as much mercury as will fill it to the middle points of

the two glass sections when these points are at the same level.

This adjustment should be made by the teacher (or, if by a student, under the eye of the teacher) as follows: (1) Set the tubes so that the middle points of the glass sections are at the same level. (2) Turn the clamp screw backward, and loosen the capping disk so as to allow free passage of air under it. (3) Pour mercury through a funnel into the open section till it stands at the middle points of the two glass sections. (4) Adjust the capping disk, and force it down by the clamp screw till it closes the tube air-tight. The board is secured to the table in an upright position by screws, or by clamping in a vice or carpenter's hand-screw. A mercurial.

(*b*) A mercurial, or aneroid barometer, and a thermometer are provided.

Operations. — (*a*) Note the temperature of the air near the apparatus. It should be kept constant throughout the experiment.

(*b*) Adjust the open tube at the greatest convenient height, and the closed tube at the least. Read and record the following: (1) The height of the barometer, B, in cm.; (2) the level, s, of the mercury in the open tube; (3) the level, s', of the mercury in the closed tube; (4) the level, e, of the upper end of the air column inside the closed tube. Read from the *middle* of the meniscus, estimating, if practicable, to the hundredth of a centimeter.

(*c*) Lower the open tube and raise the closed tube each a few centimeters, and take a new set of four readings as before.

(*d*) Continue the process until the open tube is at the lowest convenient point, and the closed tube at the highest. Obtain one set with the mercury at the same level in both tubes.

Data and Calculations. — Let a represent the internal sectional area of the glass tubing, l ($= e - s'$), the length of the column of confined air, and h ($= s - s'$, positive or negative), the difference of level between the two mercury surfaces.

(*a*) Record in tabular form, making a column for the different values of each of the following quantities: s, s', e, l, h, B, $B + h$, $(B + h) \times l$.

(*b*) State whether the values of $(B + h) \times l$ are equal within the limits of experimental errors for all values of $B + h$ and the corresponding values of l; *i.e.* is the product $(B + h) \times l$ a constant?

Theory. — Note that V, any volume of the mass of confined air $= al$, and that P, the corresponding resultant downward pressure (in grams) of the atmosphere and mercury upon the confined air = the volume of the mercury column $(B + h) \times$ specific gravity of mercury $= a\,(B + h)\,13.6$ (Why?) Evidently, now if $(B + h)\,l = K'$, a constant, then $al \times a\,(B + h)\,13.6 = K$, another constant. (Because it consists of K' and the constant factors a and 13.6.) Substituting V and P for their values al and $a\,(B + h)\,13.6$, we have $VP = K$. For similar reasons, $V'P'$, any product of another volume of this mass of gas and its corresponding pressure $= K$. $\therefore VP = V'P'$. Also, $\frac{V}{V'} = \frac{P'}{P}$. (Why?)

Inference. — (*a*) Write a general verbal statement of the meaning of the equation, $VP = K$, and also of the meaning of the equation, $\frac{V}{V'} = \frac{P'}{P}$.

(*b*) Do your results verify these two statements?

Sources of Error. — These are: (*a*) Any cause tending to change the temperature of the confined air or mercury. Hence, avoid letting the hands, the breath, or sunshine come into contact with them.

(*b*) Parallax.

(*c*) Air or other impurities mixed with the mercury.

(*d*) Leakage, inward or outward, changing the mass of confined air. This will not occur if the capping disk is tight and the rubber tube is securely wired and cemented to the glass tubes.

Part B

GRAPHIC REPRESENTATION

Reference. — Review Exercise 11, Part C.

Purpose. — It is proposed to plot a curve showing the relation between the pressures on a given mass of gas and the corresponding volumes, taken from the tabulated results of Part A.

Operations. — (*a*) Let the ordinates represent the values of $B + h$ observed in Part A, and the abscissas the corresponding values of l. Choose such a scale for the ordinates that the greatest value of $B + h$ shall be represented by a line somewhat shorter than

the length of the page. Also choose such a scale for the abscissas that the greatest value of l shall be represented by a line somewhat shorter than the width of the page.

(b) Locate the points of the curve and record all the data precisely as directed in Exercise 11, Part C.

Lessons. — If made from accurate data and correctly plotted, the curve will be a hyperbola. This is the name given by mathematicians to the class of curves which may be represented by the general equation $xy = A$, a constant.

By inspecting the direction that the curve takes with respect to the x-axis, try to interpret it so as to predict the value of the volume which corresponds to zero pressure. Also, from the direction which the curve tends to take with respect to the y-axis, try to infer the amount of the pressure necessary to reduce the volume to zero. Can the curve pass through the origin?

Notice that you found by your experiment that $(B+h)l=K$, a constant, which equation is identical in form with the above. Therefore, if you had not been directed to multiply $B + h$ by l, and had no suspicion that the products thus obtained would have a constant value; nevertheless, by plotting the curve and getting one whose law is $xy = A$, you could have learned from the curve that xy, the product of any abscissa and its corresponding ordinate, is a constant quantity. Now, in this particular case, $(B + h)l$ is the xy and is therefore a constant. Whence by this convenient method of examining your results you might have discovered Boyle's Law.

To find whether or not the curve is really a hyperbola, put the equation $xy = A$ into the form $y = A\left(\frac{1}{x}\right)$. Since this equation is now of the *same form* as that of the *straight line* ($y = ax$), it appears that if we plot a new "curve" with the values of y for ordinates, and the values of $\frac{1}{x}$ for abscissas, the line thus plotted should be straight. If it proves to be so, we shall know

that we were correct in thinking that the first curve is defined by the equation $y=A\left(\frac{1}{x}\right)$ or $xy=A$, and that it is therefore a hyperbola as we supposed. Take the values of $B+h$ from your tabulated results for the ordinates, and having obtained by division the values of $\frac{1}{l}$, take them for the abscissas and plot a new curve. If the line thus plotted is straight, then (since in the case of a straight line the abscissas are directly proportional to their ordinates) it follows that

$$\frac{(B+h)_1}{(B+h)_2}=\frac{\frac{1}{l_1}}{\frac{1}{l_2}}=\frac{l_2}{l_1}.$$

Whence $$(B+h)_1 l_1=(B+h)_2 l_2.$$

That is, $(B+h)l$ is a constant quantity.

Thus the law might have been demonstrated without previous knowledge of it.

CHAPTER IV

HEAT

Exercise Number 16

THERMOMETER

References

A 216–221, 235, 240	H 235–245, 272, 274, 277, 286
C 131–133, 220–223, 229–232, 243–245	H & W 121, 167, 168, 177, 184, 186, 187
C & C 305–315, 331, 337	J 1–9, 12, 41–43, 47, 50–54, 56
GE 126–128, 145, 149, 150	S 83–96, 119, 120, 130, 131
GP 206–214, 239, 248, 262	W & H 90, 94, 99, 102, 104

Purpose. — The purpose of this exercise is to test the boiling and freezing points of a centigrade thermometer.

Apparatus. — This consists of a boiler with a tight-fitting top terminating in a vertical tube, a Bunsen burner, and the thermometer to be tested. A supply of pure water and a vessel of cracked ice or snow are also provided.

Operations. — (*a*) See to it that the boiler is half full of water; then fit the cover

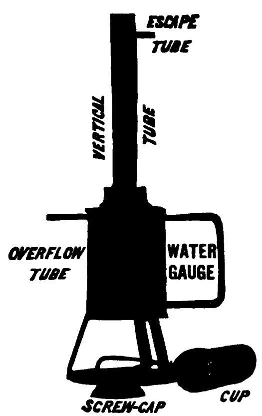

Fig. 18. — The boiler.

tightly to it, and also cork the lower or overflow tube.

(*b*) Holding a lighted match 5 *or* 6 *inches* above the burner, turn on the gas and allow it to ignite. *The gas must never be allowed to burn on the inside of the tube.* Place the flame under the boiler. ***Be very careful not to let the water boil away*** during the operations, or *the apparatus will be ruined.*

(*c*) While the water is heating place the thermometer bulb, and all that part of the tube below the zero mark, in the mass of cracked ice. Use a pencil or a sharp-pointed stick to make an opening for the thermometer; and insert the instrument carefully lest it be broken.

The interstices between the lumps of ice should be filled with water.

Wait till the mercury becomes stationary, and then, with great care, read the instrument to the tenth of a degree. In order to average the errors of observation, take several readings; and if they do not exactly agree, record the mean. ***Be very careful to avoid parallax.****

The vessel of ice should not be near a flame or a radiator. The ice must be kept thoroughly in contact with the thermometer bulb, and the instrument should not be lifted any farther out of the mixture than is necessary to observe the top of the mercury column.

* Place the eye so that the division line looks *straight* at the point of reading. If the eye is too high, the lines will be convex downward, if too low, convex upward.

(*d*) Remove the thermometer to the boiler; suspend it securely by a wire passed through a cork, slowly lower it through the tube at the top of the boiler, and close the opening with the cork. *The bulb should not be in the water. Keep your fingers out of the steam. Be very careful not to break the glass loop by which the thermometer hangs.*

(*e*) When the thermometer has come to the temperature of the steam, the mercury will remain stationary. After time has been given for this, lift the thermometer by the wire till the top of the mercury column is just visible, and read its position accurately to the tenth of a degree. Take several independent readings; and if the values vary, record the average. Now turn off the gas.

(*f*) Having first read and recorded the indication of the attached thermometer, read and record the height of the barometric column in inches; correct it for temperature by the tables of the U. S. Weather Bureau; and reduce it to millimeters by multiplying by 25.4, the number of millimeters in an inch. (Page 70.)

(*g*) If time permits, make another determination of the freezing point, *but be very careful not to transfer the thermometer to the ice until it has cooled considerably.* (Why?)

(*h*) Correct the reading of the boiling point for atmospheric pressure by *adding* $\frac{1}{27}°$ (which reduced to a decimal = .037) for every millimeter by which the barometric reading *is less than* 760, or *subtracting* this amount for every millimeter by which it *exceeds* 760.

Data. — Record in tabular form.

Numerical Data	First Trial	Second Trial
Number of the thermometer		
Barometer reading in inches		
* Reading of the "attached thermometer" in degrees F.		
* Amount of temperature correction in inches		
* Barometer reading, corrected for temperature, in inches		
* Barometer reading, corrected, expressed in millimeters		
Boiling point observed during the test in degrees C.		
Amount of correction for atmospheric pressure in degrees C.		
Boiling point of the thermometer tested, at 760 mm. pressure		
Amount of boiling-point error in degrees C.		
Freezing point of the thermometer tested in degrees C.		
Amount of freezing-point error in degrees C.		

* In case the teacher directs that the correction of the barometer for temperature is to be omitted, the data marked by asterisks will not be needed, and the barometer, if provided with a metric scale, should be read in millimeters.

NOTE. — The boiling-point error is found by taking the difference between 100° (the correct boiling point at 760 mm. pressure) and the boiling point of the thermometer that is being tested (also at 760 mm. pressure). In order to correct the readings, the amount of this error is to be *added* if the thermometer reads too low or *subtracted* if it reads too high.

The amount of the correction for $n°$ is $\frac{n}{100}$ of the correction for 100°. Thus, if the correction at the boiling point is .5°, at 70° the correction is $\frac{70}{100}$ of $.5° = .35°$.

The freezing-point error is the difference between the freezing-point reading and 0° (the correct freezing point), to be *added* if the thermometer reads too low and to be *subtracted* if it reads too high.

If both the freezing and the boiling points are in error, and a reading is to be corrected, the freezing-point correction must first be applied, and then the boiling-point correction, as directed above.

Sources of Error. — The principal sources of error are parallax and personal equation. Errors may also arise from taking the readings before the thermometer acquires the temperature of the ice or of the steam.

Lessons. — This exercise is intended to give familiarity with the construction and elementary theory of the thermometer and with some of the precautions and corrections which are to be regarded in its use.

The exact measurement of quantities of heat energy involved in chemical and engineering processes is of fundamental importance in our modern material development, as well as in science. Much of it has been gained through observations by mercurial thermometers. When calibrated by comparison with a standard air thermometer, a mercurial thermometer can be made to give very accurate readings.

Exercise Number 17

SPECIFIC HEAT

References

A 225–226, 309–311, 242, 247	H 281–283, 253, 254, 258, 262
C 246–248, 224–226, 229–232	H & W 205–210, 197–199, 202
C & C 325–328, 343–347, 350, 351	J 35–40, 68–70, 86–91
GE 130–135, 158, 159, 163	S 113–118, 154, 157
GP 219–224, 257, 382	W & H 107–109, 121–123, 125

Purpose. — In this experiment the specific heat of a metal is to be determined by the method of mixtures.

Apparatus. — This consists of the following: —

(*a*) Balance, weights, and pincers.

(*b*) The boiler of Exercise 16, with the cup which fits into the boiler in place of the cover.

(*c*) A Bunsen burner.

(*d*) A calorimeter, consisting of a cup of thin brass, nickel plated, supported upon a cork in a jar or box, and packed around with cotton-batting or felt.

(*e*) Perforated wooden covers for the cup and calorimeter.

(*f*) Two thermometers.

Materials. — The substance whose specific heat is to be determined, may be in the form of punchings or short clippings of wire or a loose roll of the sheet metal. A supply of cold water should also be at hand.

Operations. — (*a*) Half fill the boiler with water and place the Bunsen flame under it.

(*b*) See that the metal has been thoroughly dried, either on top of a radiator, or in a drying oven, and

weigh it to .1 g. If the metal is in loose form, it may be weighed in the calorimeter.

(*c*) Transfer the metal to the cup, insert the latter in the boiler, put on the cover, and *cautiously* thrust the thermometer through the perforation into the midst of the metal.

(*d*) Weigh the calorimeter; place in it the amount of water specified by the instructor; and, having dried the outside, weigh it to .1 g. Place a thermometer in the water, stirring it occasionally.

(*e*) When the temperature of the metal has become stationary, see that everything is in readiness for quickly transferring the metal and water to the calorimeter. It is best to have the boiler at the right hand, the calorimeter at the left.

(*f*) Now read the temperature of the water and the metal to .1°, as nearly as possible at the same moment.

(*g*) *Immediately* after these temperatures are taken remove the thermometers, slightly tilt the calorimeter toward the cup with the left hand, carry the cup, with the right hand, toward the calorimeter, and empty the metal into it, by quickly inverting the cup over the calorimeter. Instantly cover the calorimeter; insert its thermometer through the perforated cover; and cautiously stir the metal and water together by means of the thermometer, watching the mercury column attentively.

(*h*) When the temperature has reached its highest point, if ascending, or its lowest if descending, record its reading to .1° as the temperature of the mixture.

(*i*) Dry the calorimeter and return the metal.

Remarks. Calculations. — (*a*) Great care should be taken not to spill any of the metal or water after it has been weighed. (Why?)

(*b*) In this exercise two students can work together, dividing operations so as to save time, especially at critical moments. Thus the first may read the temperature of the metal and transfer it to the calorimeter, the second taking the temperature of the water, and so on throughout. The division of labor should be planned before beginning the experiment.

(*c*) The mass of the water is obtained by subtracting that of the calorimeter from that of the calorimeter and water; and that of the metal is obtained in a similar manner.

(*d*) The relative amounts of metal and water should be so chosen as to have the mixture come as nearly as possible to the temperature of the room. Thus the errors due to radiation and conduction will be nearly eliminated. (Why?)

To secure the best results, the water should be ten degrees or more below the temperature of the room; and the relative masses, so chosen that the mass of the water multiplied by the difference between its temperature and that of the room equals the mass of the metal multiplied by the difference between its temperature and that of the room, multiplied by its specific heat. The teacher may well make a preliminary experiment and calculation, and roughly indicate the amounts of metal and water. The actual amounts will necessarily depend on the size of the calorimeter and the kind of metal used. For a calorimeter of about 350 cc. capacity, 300 g. of copper and 100 g. of water are approximately the right proportions.

(*e*) If the water is not cool enough to give a suitable temperature range (at least 10°), it should be kept cool by a bit of ice. *No unmelted ice should remain in the calorimeter, however, at the time of mixing.*

(*f*) If but one thermometer is available, the temperature of the metal must be taken when it has become stationary, and the thermometer transferred to the water in order to get the temperature of the water and calorimeter.

Data. — Tabulate the quantities as indicated below.

Name of metal		
Temperature of metal	t_m	°C
Temperature of mixture	t	
Temperature range of metal	$t_m - t$	
Mass of metal and calorimeter		g
Mass of calorimeter	M_c	
Mass of metal	M_m	
Amount of heat given out by metal	$S_m \times M_m \times (t_m - t)$	calories
Temperature of mixture	t	°C
Temperature of water	t_w	
Temperature range of water	$t - t_w$	
Mass of water and calorimeter		g
Mass of calorimeter		
Mass of water	M_w	
Amount of heat absorbed by water	$1 \times M_w \times (t - t_w)$	calories
Temperature of mixture	t	°C
Temperature of calorimeter	$t_c\ (= t_w)$	
Temperature range of calorimeter	$t - t_c$	
Mass of calorimeter	M_c	g
Amount of heat absorbed by calorimeter	$\frac{1}{2} \times .09 \times M_c \times (t - t_c)$	calories
Specific heat of the metal	$S_m =$	

Heat Equation. — Equate the total amount of heat given out by the metal with the total amount absorbed by the water and calorimeter. (Why?)

S_m is the only unknown quantity. Solve the equation and find it.

Sources of Error. — (*a*) Those involved in the temperature readings are most important, an error of .1° in a range of 10° amounting to 1%. Hence the temperature range of the water should be made as large as practicable. (How?)

(*b*) Errors also occur in mass determination, and from losses or gains of heat by radiation and conduction.

(*c*) Since the calorimeter does not wholly come into contact with the mixture, only part of it is subject to the entire temperature range. If less than half filled it is fair to assume that half its mass changes temperature; and the error involved in this assumption is small, because its thermal capacity is relatively small. If a larger portion is filled, a correspondingly larger fraction should be assumed.

(*d*) Any loss of time in mixing, after reading the temperatures, and any loss of metal or water by spilling causes errors. (Why?)

Lessons. — Practice is given in the determination of an important physical constant, and in the use of the requisite apparatus, and in handling the equations pertaining to the transference of heat units when temperature changes take place.

Try to explain the enormous effects of the large specific heat of water on climate.

Exercise Number 18

LATENT HEAT OF FUSION

References

A 244, 245 *a*	GE 145–148	J 43
C 249	GP 239, 243	S 119
C & C 329–333	H 284	W & H 112, 114
	H & W 211, 219, 220	

Purpose. — The latent heat of fusion of ice is to be determined.

Apparatus. — The boiler, calorimeter, scales, weights, pincers, and two thermometers are needed.

Materials. — The materials used are cracked ice, or snow, and water.

Operations. — (*a*) Place a thermometer in the calorimeter, and, after a while, note its temperature.

(*b*) Thoroughly cleanse the boiler, if necessary; half fill it with water and heat it.

(*c*) Weigh the calorimeter.

(*d*) When the water is nearly at the boiling point, pour into a beaker as much as will fill about two-thirds of the calorimeter, and determine the mass of the beaker and water.

(*e*) Meantime, have ready on a cloth or blotting-paper, in the coolest place available, about as much cracked ice as, when melted, will fill one-third of the calorimeter. It is to be kept as dry as possible till used.

(*f*) When the water has cooled to about 70° C., take its temperature to the tenth of a degree, and

immediately pour into the calorimeter the ice, and then as much of the warm water as will nearly fill it. Instantly, put on the perforated cover, insert a thermometer, and with it keep stirring the mixture until the ice is melted. *Stir gently, so as not to break the thermometer.*

(*g*) Watch the mercury, which will become stationary for a moment just as the ice disappears; at this moment read and record the temperature of the mixture.

(*h*) Weigh the calorimeter and its contents; also weigh the beaker with any water that may have remained in it.

Calculations. — To get the mass of the water used, subtract the mass of the beaker and water remaining in it from the mass of the beaker and water before pouring.

To get the mass of the ice, add the mass of the water to that of the calorimeter, and subtract this sum from the combined mass of the calorimeter and its total contents.

The temperatures should be read as accurately as possible to the tenth of a degree.

The weighings are more than sufficiently accurate if made to the tenth of a gram. (Why?)

Data. — Tabulate the observations as indicated on the following page. The factor .09 in the quantity of heat gained or lost by the calorimeter is the specific heat of the brass of which the calorimeter is made.

Temperature of water	t_w	°
Temperature of mixture	t	°
Temp. range of water	$t_w - t$	°
Mass of beaker and water		g.
Mass of emptied beaker		g.
Mass of water	M_w	g.
Heat given out by water	$1 \times M_w \times (t_w - t)$	calories
Temp. of calorimeter	t_c	°
Temperature of mixture	t	°
Temp. range of calorimeter	$\left\{\begin{array}{c} t_c - t \\ \text{or} \\ t - t_c \end{array}\right.$	°
Mass of calorimeter	M_c	g.
Heat $\left\{\begin{array}{c}\text{lost}\\ \text{or}\\ \text{gained}\end{array}\right\}$ by calorimeter	$\left\{\begin{array}{c} .09 \times M_c \times (t_c - t) \\ \text{or} \\ .09 \times M_c \times (t - t_c) \end{array}\right.$	calories
Mass of calorimeter and total contents		g.
Mass of calorimeter and water	$M_c + M_w$	g.
Mass of ice	M_i	g.
Heat absorbed by ice in melting	$L_i \times M_i$	calories
Heat absorbed by melted ice in warming to t_m	$1 \times M_i \times (t - o)$	calories
Latent heat of ice	L_i (calories per gram)	

Heat Equation. — Equate the total quantity of heat absorbed with the total quantity given out. (Why?) Solve for L_i, the latent heat of ice, which is the only unknown quantity.

If the calorimeter changes temperature, the quantity of heat lost or gained by it should be properly placed in the equation; thus, if its temperature was *higher* than that of the mixture, the calorimeter *lost* heat, and the amount lost should be added to that *lost by the water.*

Sources of Error. — (*a*) State the kinds of errors to which this experiment is liable in common with the preceding one.

(*b*) What additional error may arise from wetness of the ice?

(*c*) If the ice or snow is collected from out doors when the atmospheric temperature is considerably below freezing, what source of error is present? How may this further error be corrected or eliminated?

Lessons. — The exercise affords practice in the manipulations of heat measurement, and in the principles and methods employed in solving problems pertaining to heat transferences when the latent heat of melting is involved.

Large quantities of heat (molecular kinetic energy) must be transformed into molecular potential energy in order that ice may be melted. The reverse transformation occurs whenever water freezes. Try to explain in detail the applications of these facts to refrigerators and ice-cream freezers, and to the prevention of sudden changes of temperature in the vicinity of lakes. Try also to think out how the first fact operates to reduce the severity of spring freshets in ice-bound streams.

Exercise Number 19

LATENT HEAT OF VAPORIZATION

References

A 246	GP 250	H & W 213, 218
C 250	GE 149–151	J 54–55
C & C 335, 342	H 285, 286	S 126.

Purpose. — It is proposed to determine the latent heat of vaporization of water.

Apparatus. — (*a*) The boiler used in the last three exercises is to be furnished with a water-trap and delivery tube, as shown, and 18 inches of rubber gas tubing for connecting them with the boiler. All should be tightly fitted, so that steam can escape from the boiler only through the end of the delivery tube.

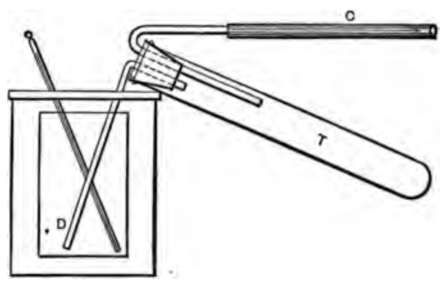

Fig. 19. — Calorimeter, cover, and water-trap: *D*, delivery tube; *T*, water-trap; *C*, rubber tube leading from boiler.

(*b*) A thick band of paper, or a wooden tube holder, is necessary for handling the hot apparatus.

(*c*) Two thermometers, balance, weights, and pincers are to be near at hand.

Operations. — (*a*) Half fill the boiler with water, generate steam, and take its temperature as in Exercise 16.

(*b*) Remove the thermometer, and lay it in a safe and convenient place. With the holder, remove the tall tubular cover from the boiler, and screw on the flat cap.*

(*c*) See that the trap and delivery tube are emptied of water, and connect them with the outlet tube of the boiler.

(*d*) Weigh the calorimeter, and having added about 200 cc. of water, weigh again. These weighings should be made while waiting for the water to boil.

(*e*) Take the temperature of the water, which should be at least 10° below that of the room. (If necessary, cool it with bits of ice before weighing. *No ice, however, should remain unmelted at the time of recording the temperature.*)

(*f*) *Immediately* after taking the temperature of the water, introduce the delivery pipe through the perforated cover, and allow steam to pass vigorously through the water. A thermometer (better previously warmed in the hand to about 10° above the temperature of the room) should be inserted through a second hole in the cover.

(*g*) Move the delivery tube about in the water, but do not place it so far below the surface that you cannot plainly hear the rattling of the collapsing steam bubbles.

(*h*) When the temperature of the mixture is as *far above* that of the room *as the water temperature*

* If the conical topped form is used, the openings should be closed with stoppers.

was below it, note the temperature of the mixture, and *at the same instant* withdraw the delivery tube and also the thermometer.

(*i*) Weigh the calorimeter with its contents, and from the three weights now recorded deduce the mass of the original water and also that of the condensed steam.

(*j*) If time permits, read the barometer and attached thermometer; correct the barometer reading for temperature as in Exercise 16, and calculate the temperature of the steam by *adding* to 100° .037° for every millimeter by which the barometer column stands *above* 760 mm., or *subtracting* .037° for every millimeter by which the barometer column stands *below* 760 mm. The boiling point thus calculated is likely to be more nearly correct than that taken by the thermometer.

Data. — Enter all the observations as soon as they are taken, in a ruled tabular form like that on the next page.

Heat Equation. — Equate the sum of the quantities of heat absorbed by the water and the calorimeter, with the sum of the quantities given out by the steam in condensing and by the resulting water in cooling to $t°$; and solve for L_s, the latent heat of steam, which is the only unknown quantity.

Sources of Error. — (*a*) State those pertaining to each kind of observation, and to radiation and conduction. Explain how they are provided against by the methods adopted.

(*b*) Against what very important error dose the water trap provide?

NUMERICAL DATA

Temperature of the water	t_w	° C.
Temperature of the mixture	t	° C.
Temperature range of water	$t - t_w$	° C.
Mass of calorimeter and water		g.
Mass of calorimeter		g.
Mass of water	M_w	g.
Quantity of heat absorbed by water	$1 \times M_w \times (t - t_w)$	calories
Quantity of heat absorbed by calorimeter	$.09 \times M_c \times (t - t_w) \times \frac{1}{2}$	calories
Mass of calorimeter, water, and condensed steam		g.
Mass of calorimeter and water		g.
Mass of condensed steam	M_s	g.
Quantity of heat yielded by steam while condensing	$L_s \times M_s$	calories
Temperature of the steam, *i.e.* boiling point	t_s	° C.
Temperature range of condensed steam	$t_s - t$	° C.
Quantity of heat yielded by condensed steam in cooling	$1 \times (t_s - t) \times M_s$	calories
Latent heat of steam	L_s	calories per gram

Lessons.—These are similar to those derived from the two preceding exercises. The student should state them concisely.

What fundamental principle of Physics is assumed in the heat equations of Exercises 17, 18, and 19?

Try to think out the applications of the high latent heat of vaporization of water and other liquids in the following cases: steam-heating apparatus, effect of evaporation and condensation in modifying atmospheric temperature, prevention of too rapid evaporation and condensation of moisture in nature, severity of burns caused by steam, loss of energy in a non-condensing steam engine, effect of moist winds in the distribution of atmospheric temperature, porous water-coolers, cooling effect of bay rum, relief from excessive bodily heat by perspiration and fanning, ice-machines, solidification of liquefied gases by their own evaporation, the production of extreme low temperatures by the evaporation of liquid air.

CHAPTER V

MAGNETISM AND ELECTRICITY

Exercise Number 20

LINES OF MAGNETIC FORCE

References

A 365–369	GE 337–343	H & W 221–226
C 256–268	GP 486–494	W & H 240–251
C & C 358–377	H 291–301	JJ 68–87
S 221–225	T 84–89, 119–121, 126–128, 142	

Purpose. — The purpose of this exercise is to determine the positions and directions of the lines of force in the magnetic fields of bar-magnets.

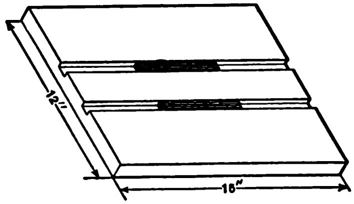

Fig. 20.

Apparatus. — This consists of two bar-magnets, a box of fine iron filings, a sifter, a small compass, a board with grooves as shown, and a square of window-glass or glazed paper of the same size as the board. The sifter is either a square of fine wire gauze with its edges bent up, or a little bag of muslin.

PART A

Operations and Observations. — (*a*) Place a magnet in one of the grooves and near the centre of the board. The flat surface of the magnet should not project above that of the board. Lay the glass or paper over the magnet and fasten it down with bits of soft wax or with thumb-tacks.

(*b*) Determine the poles of the magnet. The north-seeking pole is that which repels the north-seeking pole of the compass-needle. (Why?)

(*c*) Place some filings in the sifter, and by gently tapping it with a pencil sift the finest iron dust through it upon the glass (or paper), distributing them evenly, but *not too thickly*, all over the space around the magnet.

(*d*) Tap the board very lightly with the pencil or a ruler, using *vertical* blows only, and striking at different points successively until the filings have come into their positions of equilibrium in response to the resultant magnetic forces acting upon them in their respective parts of the field.

(*e*) Now, upon the note-book page make a diagram of the magnet and the filings. The copy of the outlines of the magnet, and of the curves into which the filings have settled in all parts of the field, should be as faithful as you can make it. If not of the same size, the proportions should be carefully preserved. Letter the poles *N* and *S*.

(*f*) Place the compass, successively, near each corner of the magnet, and also opposite the middle

of each end and of each side; at each of these points observe the position into which the needle settles; and at the corresponding position on the diagram draw a short arrow with its point in the position of the north-seeking pole of the needle.

(*g*) Remembering that the *lines represented* by the filings are *not broken*, but *continuous*, draw several of these *full* lines on each side of the axis of the magnet. Note that they are *closed curves* (but not circles or ellipses), each one passing out of the north-seeking pole of the magnet and around on the outside toward the south-seeking pole, then through the body of the magnet to the point where you began to trace it. Note also that the curves are bisymmetrical with respect to the axis of the magnet.

(*h*) Over the diagram write the heading, Field of a Single Bar Magnet; and under it write, "Each line of force represents at any point the direction which a free north-seeking pole would take at that point in consequence of the resultant magnetic force."

PART B

(*a*) Arrange the magnets as shown in either diagram (Figure 21), and repeat all the operations, again drawing arrows at the characteristic points of the field.

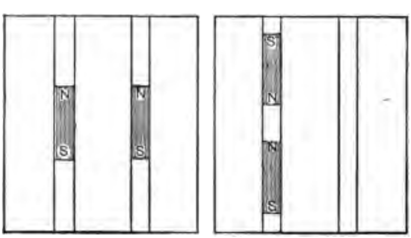

FIG. 21.

(*b*) Above the

diagram write the heading, Field of Two Bar Magnets, Side by Side (or End to End), Like Poles Adjacent; and below the diagram state what the lines represent, as before.

Part C

(*a*) Place the magnets as in one of the diagrams of Figure 21, — the one not chosen in Part B, — but reverse one of the magnets so that unlike poles shall be adjacent.

(*b*) Make all observations and records as in the preceding cases.

Inferences and Lessons. — (*a*) Is the magnetic field confined to the plane of the board, or does it include all planes? How can this be proved?

(*b*) In each case, where is the strength of field the greatest?

(*c*) Show by small diagrams the arrangement of the lines of force between two poles that are repelling each other and between two poles that are attracting each other, and label them appropriately.

(*d*) In investigating magnetic properties and their consequences it is very important to know definitely the directions of the lines of force and the relative strengths of different parts of the field.

Additional Work. — If there is time (*a*) place a small rectangle of soft sheet-iron between the two poles in the arrangements of Parts B and C, and sketch the field, stating concisely what changes in the paths of the lines are due to the *permeability* of the soft iron.

(*b*) Map the lines about a bar magnet pole in a plane perpendicular to the axis of the magnet.

(*c*) Map the field of a horseshoe magnet lying flat and also with poles up.

(*d*) Very pretty results may be obtained by mapping the field of three or more magnets arranged in a triangle, square, pentagon, cross, etc.

Permanent Maps. — If the student does something in photography, he will find it very fascinating to repeat these experiments in a dark room, using a photographic plate instead of the glass or paper. Make the map by ruby light on a slow or medium plate, exposing to the light of a match at one or two feet distance, then developing and fixing in the ordinary way. Developing or printing-out papers also give excellent results. In all cases carefully avoid over-exposure.

Another method is to coat a sheet of ordinary glass with shellac varnish; dry it; make the map; and then warm it on a sand-bath over a stove until the shellac softens and the filings sink into it.

Maps made on glass, when backed with ground or opal glass and bound or framed for transparencies, will make pretty ornaments.

Pieces of watchspring, straightened and magnetized, make excellent magnets for all these experiments, and cost nothing.

Exercise Number 21

FIELD OF ELECTROMAGNETIC FORCE

References

A 375, 377, 381	GE 349–354, 308, 309	H & W 252
C 269, 270, 291, 315, 317–319	GP 445, 507–514	JJ 119–126
C & C 452–459	H 371–376	S 226–228
T 195–204, 389, 390, 393	W & H 278, 281–284	

Purpose. — It is proposed to investigate the magnetic field about a current-bearing conductor.

(*a*) When straight. (*b*) When in a single loop. (*c*) When in a helix. (*d*) When in a flat coil. (*e*) When the helix or coil is associated with a soft iron core.

Apparatus. — The apparatus and its arrangement are shown in the diagram. A drawing made from the objects themselves should be placed in the note-

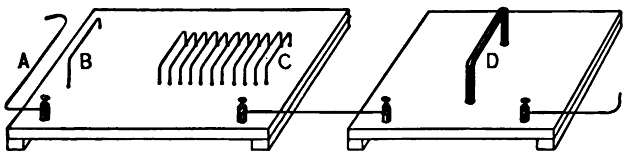

Fig. 22. — Conductors arranged so that their fields of electromagnetic force can be mapped.

book. Iron filings, sifter, and compass are provided as in Exercise 20; also a square and a rectangle of soft sheet-iron.

Operations and Observations. — (*a*) Dip the bare wire, *A*, into the box of filings, and make a sketch of what you see.

(*b*) Sift filings over the two boards, tap the boards till the filings find their places, disconnect the current and sketch the fields about *B*, *C*, and *D*. *If you are using the dynamo current in series with other tables, do not disconnect.* The teacher will attend to that.

(*c*) Place the compass in the characteristic parts of each field, *B*, *C*, *D*, and draw *thin* arrows in corresponding positions in your diagrams just as in Exercise 20.

(*d*) Place the rectangular strip of sheet iron lengthwise in the helix, *C*, but not touching it, and similarly place the square in the flat circular coil, *D*, repeat operations (*b*) and (*c*), making new diagrams, or stating each effect in words, as preferred.

(*e*) The direction of the current will be given you by the teacher. Indicate it by *short, thick* arrows in all parts of the circuit and especially near the coils.

(*f*) Do not crowd the diagrams, nor make them too small. It is better to put only one drawing on a page. Label the fields, Straight Wire, Helix, etc.

Inferences and Lessons. — Make clear, concise sentences answering the questions below.

(*a*) What is the form of a line of force about *A* or *B*?

(*b*) Looking along the wire in each case *with* the direction of the current, do the lines of force go clockwise or counter-clockwise?

(*c*) What is the direction of the lines of force if the current is coming *toward* you?

(*d*) Is the field of *C* what it should be if the lines of force are the resultants of the lines of force of several loops like the single one *B*?

(*e*) Compare the fields of *C* and *D* with those which would belong to similarly shaped bar magnets.

(*f*) How is the strength of field affected by using several loops in a compact coil instead of a single loop, provided the strength of the current is the same?

(*g*) What effects are due to the permeability of the soft iron cores?

What is the name given to a helix or flat coil having a soft iron core and carrying a current?

(*h*) What can you infer as to the behavior of all such coils and helixes toward each other and toward magnets? Try to find applications of electromagnets.

NOTE. — The upper surfaces of the boards are very smooth and painted white or else covered with white glazed paper which was glued on before drilling the holes. The binding posts may be omitted and their places taken by double connectors. The wire of A, B, and C, is No. 16 bare copper; of D, No. 16 cotton-covered magnet wire. The required current is best furnished by a direct current dynamo or storage battery, all the apparatus in the laboratory being joined up in series. In this case the teacher will regulate the current by means of a suitable resistance, and inspect the connections before turning on the current.

In case the school is not provided with a dynamo and the tables are not wired, one or two chromic acid cells are to be connected in series with each apparatus.

EXERCISE NUMBER 22

STUDY OF A SIMPLE VOLTAIC CELL

REFERENCES

A 346–349, 385–385 *d*	H 346–355
C 294–297	H & W 243–246
C & C 428–442	JJ 30–36, 40–44, 47–55
GE 297–304, 308, 309	S 231, 234, 240
GP 429–441, 467	W & H 269–271, 274–277

Purpose. — The purpose of this exercise is to investigate the action of a simple voltaic cell.

Apparatus. — The apparatus and materials consist of a battery jar, nearly full of dilute sulphuric acid (1 part acid to 20 parts water), two zinc plates, one of them amalgamated with mercury, a copper plate,

a wooden cleat with two saw cuts in which to support the plates, a compass, and a double connector.

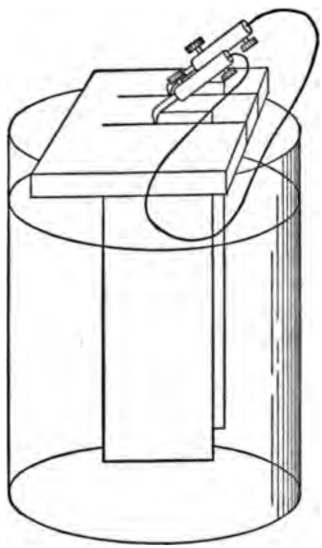

FIG. 23. — Showing method of supporting and connecting the plates.

Preliminary Directions. — (*a*) Caution! Throughout the experiment the jars and plates should be kept in a tray of sheet lead provided for the purpose. The acid is very destructive, and under no circumstances should it be allowed to drip on the table or clothing. Should such an accident occur, quickly wash away the acid with a weak ammonia solution, followed by plenty of water.

(*b*) Do not inhale the unpleasant fumes.

(*c*) Do not allow the amalgamated zinc to touch either of the other plates.

(*d*) In describing the apparatus, make a diagram showing (1) cell with plates and liquid in position, wires joined, and compass needle in the observed attitude; (2) plates, marked respectively Cu (copper) and Zn (zinc); (3) electrodes, marked respectively + electrode and − electrode; (4) solution, marked sulphuric acid.

(*e*) After each observation, remove the plates *promptly* (to a jar of water, which should stand ready in the tray).

(*f*) Before beginning each operation, see that the liquid has cleared of bubbles previously formed.

Operations. — (*a*) Place the copper strip in the acid. Is any chemical action indicated by gas bubbles rising from the plate?

(*b*) By means of the cleat, support the copper and the unamalgamated zinc side by side in the acid, not allowing either the plates or their wire terminals to touch each other. Is there now any chemical action? If so, from which plate do the bubbles come? Note, as well as you can, the rapidity of the action, so as to compare it with that in other cases.

(*c*) By means of a double connector, join the wire that leads from the copper (*i.e.* the + electrode) to the wire that leads from the zinc (*i.e.* the − electrode). Do bubbles rise from either or both plates? If from both, from which plate do the most bubbles come off? Is the action more vigorous than in Case (*b*)?

(*d*) Pass the wire in a north-south direction *over* the compass needle. Is the needle deflected? As you look along the wire, does the *north-seeking* pole move in the clockwise or counter-clockwise direction with regard to the wire? Then, remembering the relation of lines of force to current which you learned in the preceding exercise, state whether the current passes along the wire from copper to zinc, or in the reverse direction.

(*e*) Replace the unamalgamated zinc by the amalgamated, leaving the circuit open; and compare the observations with those of Case (*b*). Record the result.

(*f*) Join the electrodes. Where do the bubbles originate now? Compare the vigor of the action with that in Case (*c*). Record the result.

(*g*) Pass the wire over the compass, as in Case (*d*). Is the direction of the current the same? Is the strength of the current greater (indicated by a greater deflection)?

(*h*) Compare the two zincs, and (if possible) note which has wasted the most by the chemical action. (The only certain way is to expose them equally and weigh each before and after.) Does the copper show any signs of wasting?

(*i*) Note whether any heat energy has developed, as indicated by plates or liquids becoming warmer.

Carefully space your notes, writing them in columns headed Operations, Observations, Inferences, so that each operation and its corresponding observations and conclusions shall stand out prominently on the page.

Lessons. — (*a*) *Energy changes.* 1. If the electrodes are tested on open circuit by means of a very sensitive electroscope (or electrometer), the + electrode shows a positive electrostatic charge and the – electrode a negative charge. Chemical potential energy of zinc and acid has been transformed into electrical potential energy.

2. When the circuit is closed, this is transformed into electrokinetic energy, associated with the con-

ducting wire. 3. This energy can do several kinds of work. (What kinds?) The supply of energy is kept up at the expense of zinc and acid as long as the circuit remains closed, or until the chemical potential energy is exhausted.

(*b*) Since the zinc wastes away, and the copper does not, it is evident that the chemical change takes place at the zinc plate and not at the copper. But the hydrogen bubbles originate at the copper plate. Therefore we conclude that the chemical action is handed along from molecule to molecule through the liquid.

(*c*) Amalgamating the zinc largely prevents "local action," due to iron or carbon particles existing as impurities in the commercial zinc. By local action chemical energy is transformed into heat in the cell and is wasted, instead of being wholly transformed into electrokinetic energy, available in the external circuit.

GALVANOMETERS

References

A 414–444 *l*	GE 321–323, 332	H & W 252
C 291, 318	GP 465–468, 479	JJ 144–154
C & C 471–474	H 382–386, 393	S 230
T 208–221	W & H 278–280	

Galvanometers should be secured to a solid wall, or be placed on a shelf supported by the wall, and not connected in any way with the floor. If set up on a table, the table must be as free as possible from

any tendency to jarring or vibration. It is necessary that a good light shall fall on the scale.

Caution. — Do not attempt to make any of the galvanometer adjustments until the instructor has personally directed you. Such further instructions as are thought proper will be supplied. The adjustments described in the sentences marked thus, *, are rather difficult, and in attempting them without personal direction the inexperienced person is likely to disable the instrument.

D'Arsonval Galvanometer. — To adjust the D'Arsonval galvanometer, it must first be levelled by turning the levelling screws at the base, so that the coil

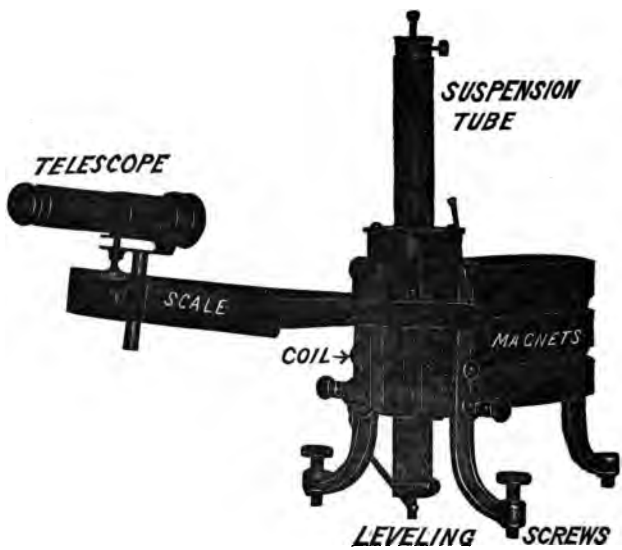

Fig. 24. — D'Arsonval Galvanometer.

can turn freely without touching either the magnets which embrace it or the core which it surrounds. The weight of the coil may be lifted off the suspension by a screw or lever, which acts upon it from behind. To lower the coil into its position for use, turn the screw or lever until the coil hangs freely by the suspension. *The adjustment of the coil to the correct height is made by raising or lowering the short rod or pin to which the suspension is attached. This pin is supported by a little collar at the top of the instrument, and is held at the proper height by a set screw.

* By loosening a set screw in the support or suspension tube, this collar can be rotated so as to bring the plane of the coil into the plane of the magnet poles.

If necessary, the levelling screws are again to be adjusted.

The indications of the instrument are read by a pointer, which swings over a scale, or by a mirror, in which a reflected image of the scale is viewed through a telescope provided with a vertical cross-hair. In the latter case the eyepiece of the telescope is focussed so that the cross-hair appears distinct. The telescope and scale are placed directly in front of the mirror, the one a little above, and the other an equal distance below the level of the centre of the mirror. The image of the scale appears in the field of view of the telescope, and if the image of the scale is not clear, the telescope must be carefully focussed by means of the draw-tube. Finally,* the telescope, the scale, or the coil (depending on the make of instru-

ment) is swung a very little to the right or left until the cross-hair coincides with the zero of the scale.

The D'Arsonval shown in Fig. 25 is read as follows: Place the eye just behind the scale, looking either through the peephole or a very little to one

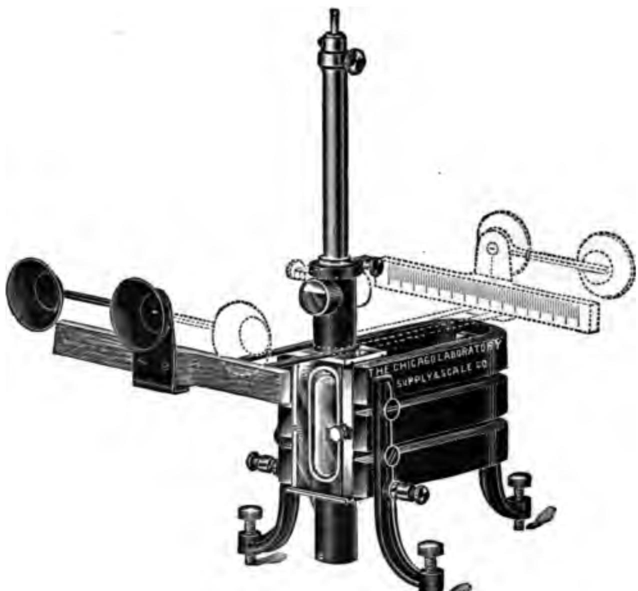

FIG. 25.—D'Arsonval Galvanometer, with sight and scale attachment.

side of it, and just on a level with the top edge of the scale. You will see a reflection of the scale in the *suspension mirror.* Also, above this *image* of the scale there will appear in the silvered upper half of the cover glass the reflection of a *vertical reference mark* that is placed above the *scale.* When the in-

strument is levelled and the coil lowered as mentioned above, the zero of the scale image will nearly coincide with the reference mark image. If it does not, the cover tube of the mirror-box is to be revolved a very little to the right or left, until the correct adjustment is secured.

Astatic Galvanometer. — This instrument must be set so that the *axis of its coil* extends east and west (or, in other words, so that the *plane of the coil* is north and south). The instrument is then levelled, and the needle adjusted to swing freely within the coil. These adjustments are similar to those described for the D'Arsonval. The needle, if properly freed from torsion and friction, will lie in a definite position; and the zero of the scale should be brought directly under the pointer.

FIG. 26. — Astatic Galvanometer.

Tangent Galvanometer. — This galvanometer, like the others, is levelled at the base; but since the *pointer* is set at right angles to the *needle*, the diameter through the two zero marks of the scale must lie east and west, and the plane of the coil must be in that of the magnetic meridian. If there is a lever or screw to lift the needle when not in use, the needle must be lowered by means of it until it swings freely on its pivot. The instrument is then rotated until

the zero marks are exactly under the ends of the pointer.

FIG. 27.—Tangent Galvanometer.

In order to be adapted to currents of different strengths, tangent galvanometers frequently have two or more coils on the same reel. If there are three coils, there will be four binding-posts. If the two posts at the left are connected with the circuit, the first coil only is placed in circuit. The two at the right throw in the third coil only, the two at the middle the second coil only. The first and third posts throw in the first two coils, the second and fourth posts the last two coils, and the first and fourth posts all three coils.

Usually, the connections are so chosen as to give the needle a deflection of about 45°, because with that reading the errors are smaller in proportion than for either larger or smaller deflections.

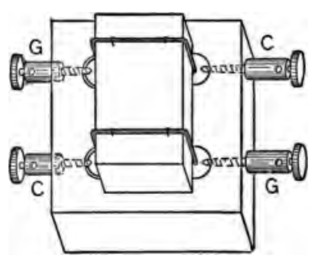

FIG. 28.—Commutator. The wires leading from the galvanometer are inserted at posts *GG*, and those leading from the current circuit at posts *CC*.

COMMUTATOR

In many experiments it is necessary that the current passing through the galvanometer be quickly reversed. Accordingly, a commutator, or reversing

switch, is provided. A convenient and inexpensive device is shown in Fig. 28.

The connections are made as shown, by wires dipping into holes containing mercury. To reverse the current through the galvanometer, lift the top, turn it through a right angle, and replace it. To break the current, simply leave off the cover.

SHUNTS

A strong current should never be sent through a sensitive galvanometer. In beginning an experiment, it is always best to shunt the galvanometer by connecting its two binding-posts across by means of a short wire, so that only a small fraction of the current goes through it. When the current is so small that the galvanometer is insensitive, a shunt of higher resistance may be used, or the shunt may be discarded.

MICROMETER SCREW CALIPER

In one kind of micrometer caliper, the pitch of the screw (distance between two adjacent threads, measured parallel to the axis) is 1 mm.; and the circumference of the head is divided by a circular scale into one hundred equal parts. In another kind, the pitch is $\frac{1}{2}$ mm.; and the circular scale has fifty equal parts.

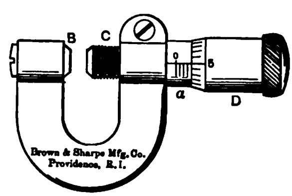

FIG. 29.—Micrometer Caliper. Pitch $\frac{1}{2}$ mm. Circular scale in 50 equal parts.

When the end of the

screw rests against the stop, *B* (without strain), the edge of the circular scale should coincide with the zero mark of the linear scale, *a* ; and the zero line of the circular scale should exactly coincide with the horizontal reference line.

It should be noticed that in the first kind of micrometer caliper, the zero mark of the circular scale is identical with the .100 mark ; and in the second kind it is identical with the .50 mark.

In the first kind of micrometer caliper, if the head of the screw is given one complete turn toward you, the screw end retires from the stop to a distance equal to the pitch of the screw (1 mm.) ; and the edge of the circular scale will coincide with the division 1 on the linear scale, which therefore denotes the distance in millimeters between the screw end and the stop. Also, the zero mark of the circular scale will again coincide with the reference mark. Now if the head be turned farther around till the division numbered 25 coincides with the reference line, the screw has retired from the stop a further distance equal to twenty-five hundredths of the pitch of the screw (*i.e.* .25 mm.). Similarly, if the screw has been turned so that the linear scale shows seven and a fraction of its millimeter spaces, and the 69th division of the circular scale coincides with the reference line, it is clear that the screw has turned through seven and sixty-nine hundredths revolutions, and the screw end is distant from the stop just 7.69 mm.

To Measure the Diameter of a Wire. — (*a*) Withdraw the screw from the stop and place a *straight*

portion of the wire between them, so that it *lies flat* against the face of the stop. Turn the head till the face of the screw end rests against the wire firmly enough so that you can *just feel* the resistance.

(*b*) *To read the First Kind of Caliper.* — With the line of sight perpendicular to the scales at the reference line, read the number of whole millimeters on the linear scale, and the number of tenths and hundredths of millimeters on the circular scale.

(*c*) Determine the zero error by setting the screw end gently against the stop, and observing the scale readings as before. If the zero of the circular scale coincides with the reference line, no correction is required. If there is a small *negative* reading, it must be *added* to all readings of the caliper; and if there is a small *positive* reading, it must be *subtracted.* (Why?)

(*d*) *To read the Second Kind of Caliper.* — In this case also, each division of the circular scale corresponds to one-hundredth of a millimeter (because $\frac{1}{50}$ of $\frac{1}{2}$ mm. $= \frac{1}{100}$ mm.). Read the number of whole millimeters on the linear scale, and add the hundredths indicated on the circular scale just as directed above; but *if the fractional part of a millimeter exposed on the linear scale is greater than one-half, then* .50 *must be added* to the reading, in order to state correctly the fractional part. (Why?)

Thus, in Fig. 29, the caliper reads 4.50 mm. If *D* were turned so as to bring *C* nearer to *B* by $\frac{5}{50}$ of a revolution, the reading would be 4.45 mm.; but if *D* were turned so as to withdraw *C* by $\frac{23}{50}$ of a

revolution, the corresponding reading would be $4.23 + .50 = 4.73$ mm.

(*e*) Several measurements should always be taken along different parts of the sample of wire. (Why?)

(*f*) Micrometers measuring in inches usually have a linear scale with units $\frac{1}{25}$ of an inch in length, and the circular scale divided into 40 equal parts. What fraction of an inch does one division of the circular scale measure?

(*g*) If the head of the screw is fairly large, it is easy to estimate tenths of the divisions of the circular scale and thus estimate thousandths of millimeters, or ten-thousandths of inches.

Exercise Number 23

ELECTRICAL RESISTANCE

References

A 350–353, 414–416
C 312, 324
C & C 460–463, 471, 473, 475, 479
GP 455, 470–473, 479
GE 315, 324–328
JJ 95, 98, 99–101, 106, 107, 151, 152, 154, 160–168
H 377–380, 383–389
H & W 256
S 230, 234, 235
W & H 279–280, 290–294

Purpose. — The purpose of this exercise is to measure the electrical resistances of wires of various dimensions and materials, to verify the laws that state the relations of resistance to length, sectional area, and substance, and to determine the resistivities of the materials of which the wires are made.

Method. — The resistances are to be measured by the method of Wheatstone's Bridge.

Theory of the Wheatstone Bridge. — Let there be an arrangement of conductors forming a divided circuit as represented in the diagram.

Let a current from the battery divide at A into two branches, and reunite at D; and let the point C be so chosen with reference to B that no current passes through a galvanometer, G, in connection with these two points. Then B and C are equipotential points. (Why?) Also, —

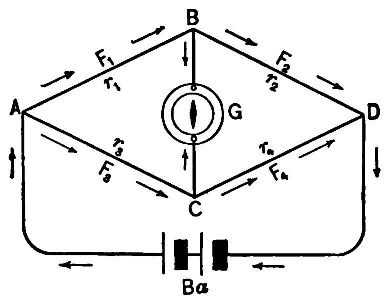

FIG. 30. — Explaining the theory of Wheatstone's Bridge.

let F_1 and r_1 be the fall of potential and the resistance between A and B,

F_2 and r_2 be the fall of potential and the resistance between B and D,

F_3 and r_3 be the fall of potential and the resistance between A and C,

F_4 and r_4 be the fall of potential and the resistance between C and D.

Then $F_1 = F_3$ (being the falls of potential from A to the equipotential points B and C),

and $F_2 = F_4$ (being the falls of potential from the equipotential points B and C to D).

$$\therefore\ \frac{F_1}{F_2}=\frac{F_3}{F_4}.\quad \text{(Why?)}$$

But $$\frac{F_1}{F_2}=\frac{r_1}{r_2} \text{ and } \frac{F_3}{F_4}=\frac{r_3}{r_4}.$$

(The fall of potential along any part of a conductor is proportional to the resistance of that part.)

$$\therefore\ \frac{r_1}{r_2}=\frac{r_3}{r_4}.\quad \text{(Why?)}$$

Corollary. — Since the resistances of conductors of uniform material and sectional area are proportional to their lengths, it follows that if *ACD* be a wire of uniform material and thickness, the ratio of the lengths of the segments *AC* and *CD* $\left(i.e.\ \frac{L_3}{L_4}\right)$, may be substituted for the ratio of their resistances $\left(\frac{r_3}{r_4}\right)$ and we shall have $\frac{r_1}{r_2}=\frac{L_3}{L_4}$. If three of the quantities in either of the above proportions are known (or can be measured), the fourth can be calculated.

Apparatus. — The apparatus consists of a D'Arsonval or an astatic galvanometer (*G*), of a Wheat-

FIG. 31 *a*. — Wheatstone's Slide-wire Bridge.

stone slide-wire bridge, shown in Fig. 31 *a* and *b*; one or two cells of battery *Ba*, in series; the wires

whose resistances and dimensions are to be determined, and a known resistance, to be used as a standard. Two pairs of thick short wires or copper strips of equal dimensions are provided for connecting in the known and the unknown resistances; and two pairs of long leading wires are also to be used for connect-

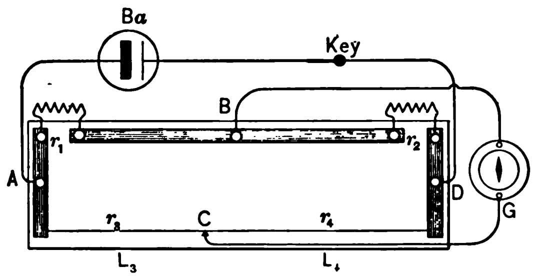

Fig. 31 *b*.—Simple form of Slide-wire Bridge, showing connections.

ing the battery and the galvanometer with the bridge. The resistances of the heavy copper conductors are negligible, except where extreme accuracy is sought. The wire is of uniform sectional area, just a meter long,* and stretched over a meter rule. It is made of an alloy (German silver, or better, platinoid), having a resistance that is relatively high and that changes little on account of ordinary temperature changes. Make a diagram or sketch of the apparatus when connected.

Part A

TO MEASURE RESISTANCE

Operations. — (*a*) By means of the binding-posts make the connections as indicated in the diagram

* In some bridges the wire is a half-meter long.

above. r_1 is the known resistance, and r_2 the unknown, or *vice versa.* See that all binding-post contacts are scraped clean and bright and are firmly set.

(*b*) Slide the contact piece along the wire until a point C is found, such that when contact is made there the galvanometer needle shows no disturbance. *Do not scrape the wire.* (Why?)

(*c*) Test the adjustment by seeing if equal and opposite deflections are caused by making contact at a very short distance on the right of this point, and then at the same distance on the left of it. If necessary, readjust till the point is found which satisfies this condition.

(*d*) Read and record in millimeters the lengths L_3 and L_4 of the segments into which C divides the wire.

(*e*) From the corollary to the general theory already given, in connection with an inspection of the diagram above, it is plain that $\frac{r_1}{r_2} = \frac{L_3}{L_4}$. Substitute the values of the three known quantities and solve for the unknown resistance.

(*f*) Now interchange the known and the unknown resistances, repeat the operations, solve the equation for the new value of the unknown resistance, and take as the true value the mean of the two determinations.

Remarks. — In making the preliminary trials for finding the point C, have the galvanometer shunted. Make contact at distances of 10 cm. along the wire, beginning at the left end, until the galvanometer re-

verses its deflection; then go backward, toward the left end, making contact at distances of 1 cm. When the point C is located within 1 cm., make contact by steps of 1 mm. Avoid any cause for heating the wire. (Why?)

It is well to place a key in the battery circuit, and to close this circuit just a little before making contact on the wire, leaving the battery circuit open at all other times. (Why?)

Part B

To verify the law of the relation of resistances to lengths, the sectional areas being equal and the temperature constant.

Operations and Data. — (*a*) On the resistance rack (Fig. 32) are 200 cm. of No. 28 German silver wire between the binding-posts A and B. (The resistance of the copper washer, I, may be neglected.) By

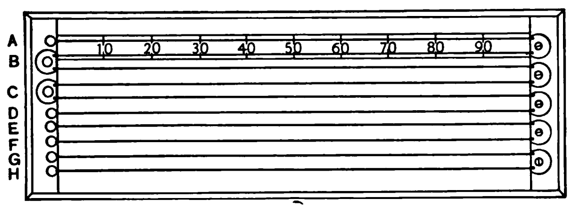

Fig. 32. — Resistance Rack.

means of the short, thick conductors provided, connect the posts at A and B with the posts at one of the openings of the bridge, and in like manner connect the terminals of a known resistance to the posts at the other opening.

(*b*) In accordance with the directions in Part A, determine the resistance of the German silver wire (on both sides of the bridge), and set out the values and their mean at the right of the calculation and near the margin of the page, so that they may be conspicuous. Also place their average beneath them.

(*c*) By means of binding-posts *B* and *D*, connect the 400 cm. of wire, and repeat the operations.

(*d*) Similarly measure the resistance of the 600 cm. between *A* and *D*.

(*e*) On a single page by itself rule a tabular form in which all the data of the exercise are to be entered. Head the page, DATA, EXERCISE 23.

Place the following headings in a vertical column: Substance; B. & S. Gauge Number; l = length (cm.); Diameter (mm.); Radius (mm.); r = radius (cm.); a = Area = $\pi^2 r$ (sq. cm.); R = resistance (ohms.); Ratio, $\frac{R}{l}$ (ohms per cm.); Ratio, $\frac{R}{a}$; Resistivity, $K = R\frac{a}{l}$. To the right of this column make a vertical column for each wire, and in it enter, when obtained, the data for that wire, opposite its proper heading.

Calculate the ratio, $\frac{R}{l}$ (ohms per centimeter), for each of the three wires, and enter it in its appropriate place. *It should be expressed as a decimal fraction.*

Inferences. — (*a*) Choosing suitable scales for the values of R and l, and using the latter as abscissas and the former as ordinates, plot a "curve" showing the relation of resistance to length. Does the curve

approach to a straight line? If so, what relation may be inferred?

(*b*) Are the values of $\frac{R}{l}$ for the three different lengths of No. 28 German silver wire nearly enough equal so that the differences may be ascribed to the errors of experiment? If so, may we write $\frac{R_1}{l_1} = \frac{R_2}{l_2} = \frac{R_3}{l_3} =$ a constant?

(*c*) Give the formal statement of the law verified.

Part C

To verify the law of the relation of resistance to sectional area, the substance, length, and temperature remaining the same.

Operations and Data. — (*a*) As in Part B, measure the resistance of the 600 cm. of No. 18 German silver wire between binding-posts E and F of the resistance rack.*

(*b*) Measure the diameters of each of the two sizes of German silver wire at several points, and if they vary, take the average for each size. *Do not measure them on the rack* unless told to do so by the instructor, as careless handling

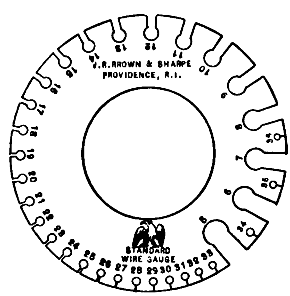

Fig. 33. — B and S Wire Gauge.

* The illustration (Fig. 32) represents only 200 cm. It is better to have 600 cm. of each of the other wires arranged like the first wire. The intermediate binding-posts are not necessary for these, however.

may stretch or displace the wires. Use samples of the same wires provided for the purpose. By means of the B. & S. wire gauge (Fig. 33), verify the gauge number of each wire. The correct number is the one opposite that slot into which a *straight portion* of the wire will *just fit* without bruising. The gauge number being ascertained, the corresponding diameter may be taken from a table of gauge numbers and diameters. A better way to determine the diameter of the wire is to measure it with the micrometer screw caliper as directed on p. 115.

(*c*) Calculate the ratio, $\frac{R}{a}$, for each of the two sizes of wire.

(*d*) Enter in tabular form all the additional data obtained in this part.

Inferences. — (*a*) Are the two values of $\frac{R}{a}$ nearly enough equal so that you may ascribe the difference to experimental errors? If so, what proportion may you write?

(*b*) State the law verified.

Part D

To determine the resistivities of wires of different materials and learn whether the substance of a wire affects its resistance.

Operations, Data, Calculations. — (*a*) Measure precisely as before the resistance of the 600 cm. of No. 28 copper wire between posts *G* and *H*,

(*b*) Obtain its diameter as in Part C.

(*c*) Having reduced the lengths and sectional areas of all the wires measured in the exercise to *centimeters* and *square centimeters*, calculate the resistivity of each wire in turn. To do this, substitute in the formula, $K = R\frac{a}{l}$, where K is the resistivity, R the resistance, a the sectional area in square centimeters, and l the length in centimeters. It represents the resistance in ohms per centimeter of a conductor one square centimeter in cross-sectional area.

(*d*) Enter all the remaining data in the tabular form.

Inferences. — (*a*) If the first two laws are true, how should the values of the resistivity of German silver obtained from the different samples of German silver wire compare with each other?

(*b*) Are the differences small enough to be ascribed to experimental errors? If there are large differences, they may be due to mistakes in calculation (look for them), or possibly to actual difference in composition of the different specimens of wire, or to variations in the temperatures at which the measurements were made.

(*c*) Compare the mean resistivity of the German silver with that of the copper by dividing the former by the latter. What is the ratio?

(*d*) State the law which is verified by the comparison made in (*c*). (Obviously a similar comparison can be made by dividing the resistance of the No. 24 German silver wire by the resistance of the No. 24 copper wire.)

Sources of Error. — State briefly the most obvious sources of error in the different operations of this exercise.

Exercise Number 24

MEASUREMENT OF CURRENT STRENGTH

References

A 357, 358, 414, 429–431
C & C 445–451, 464, 472
C 298, 307–309, 324
GP 442–444, 451, 452, 463–467, 548
GE 307, 313, 322, 332
H 365–369, 382, 393
H & W 251, 254, 255
JJ 59–67, 96, 145, 153, 155–159, 370–383
S 230, 236, 237
T 162, 178, 190, 212, 236–245, 492–496 *a*
W & H 279–280, 290–294

Purpose. — The purpose of this exercise is to measure the strength of an electric current by means of a gas voltameter, and to determine the constant of a tangent galvanometer.

Apparatus. — (*a*) The voltameter consists of a gas measuring tube, graduated in cubic centimeters, and a glass vessel containing dilute sulphuric acid, into which are inserted two electrodes of platinum or lead (Fig. 34 *a*).

(*b*) The galvanometer, a commutator (Fig. 28), and the voltameter are connected with the leading wires from the source of current, as shown (Fig. 34). To avoid spilling the acid, the voltameter should be placed in a leaden tray.

(*c*) A thermometer is suspended near the tube.

(*d*) For measuring the time, the seconds clock, or stop-watch, or an ordinary watch is needed. If a

watch is used, see that the minute hand and second hand are so set as to begin each minute simultaneously.

Operations. — (*a*) See that the galvanometer is properly levelled and set at zero, and that the connections are properly made, with the circuit closed except at one single point (at the dynamo switch, or, if the independent battery current is used, at the commutator.

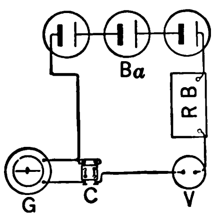

FIG. 34. — Connections for current measurement: *Ba*, battery; *V*, voltameter; *C*, commutator; *G*, galvanometer; *RB*, resistance box.

(*b*) Make sure that the electrode over which the tube is to be placed is the cathode, and that it is standing vertically upward, so that the tube can go neatly over it.

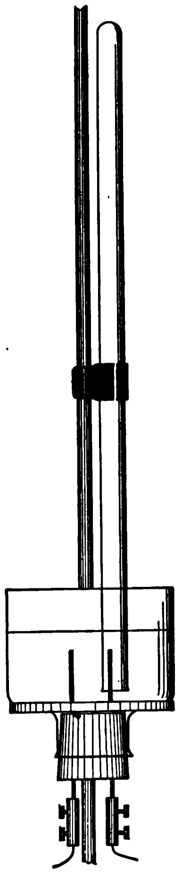

FIG. 34 *a*.—Gas Voltameter, supported by a ring and clamp.

(*c*) From a beaker pour some of the dilute acid into the tube until it is nearly filled (within two or three cubic centimeters); close the end with the thumb. Cautiously inverting the tube, place its end under the surface of the acid in the jar, and remove the thumb. Keeping the open end

of the tube beneath the surface of the acid, place it over the cathode, and support it in a vertical position by means of a screw clamp and support rod. Be careful not to touch the upper part of the tube with the hand. (Why?)

(*d*) Read the number of cubic centimeters of gas in the tube, estimating tenths of the smallest scale divisions. Read from the bottom of the meniscus. Observe the temperature. [It should be kept constant, if possible, throughout the experiment. The temperature of the acid should be the same as that of the room.]

(*e*) All being now in readiness for beginning the experiment, the circuit is closed and the time observed. At the instant of closing circuit, the person closing it will say "Now!" and at that instant the exact time (hour, minute, and second) is noted. The warning word "Ready?" should be given a few seconds before the signal "Now!"

[If the dynamo current is used, the teacher or a student will close the circuit by means of the switch at the demonstration table, all other openings having been previously closed. If the batteries are used at the students' tables, one student closes the circuit at the commutator in each circuit and another observes the time.]

(*f*) While the current is passing, a series of galvanometer readings is taken, tenths of the smallest scale divisions being estimated, and parallax carefully avoided. Read the angle of deflection at each end of the pointer. Reverse the current through the galvanometer by shifting the commutator as

nearly *instantaneously* as possible, and again read at both ends of the pointer. Before each reading, tap very gently on the frame, so as to overcome the slight friction at the pivot. Obtain as many sets of four readings each as the time of collecting the gas will permit, and record all the readings in a neat tabular form.

(*g*) When the tube is nearly full of gas (hydrogen), the circuit is to be opened and the time recorded precisely as at the beginning.

(*h*) Raise or lower the tube in the vessel as may be necessary, until the liquids are at the same level inside and out. If the voltameter vessel is not deep enough, transfer the tube to a jar.

Caution! Avoid heating the part of the tube containing the gas, either by breathing upon it or handling. Use a wooden holder or a thick band of paper. Now read and record the volume of gas above the acid surface in the tube. Read as before, from the bottom of the meniscus.

(*i*) Note the temperature, and also the barometer and attached thermometer readings.

Data. — Tabulate the results as indicated (p. 130).

Remarks. — If the source of current be a dynamo or storage battery, all the instruments at the students' tables may be in series with it, and the current must be cut down to a safe and convenient strength by means of an adjustable resistance placed in the circuit and regulated by the teacher. An advantage of connecting all in series is that since all are measuring the same current, the teacher can measure it with a meter at the demonstration table, and check the students' results by comparison with his own as well as with those of all the class.

Numerical Data

Time starting	h. — m. — s. —	Deflections	
Time stopping	h. — m. — s. —	1	°
Time interval T	sec.	2	
Tube reading (1)	cc.	3	
Tube reading (2)		4	
Volume (2)–(1) V		1	
Temperature (1)	° C	2	
Temperature (2) t	° C	3	
Barometer reading	inches	4	
Attached thermometer	° F	1	
Temperature correction	inches	2	
Corrected barometer reading, B	mm. inches	3	
Vapor pressure p	mm. inches	4	
Net pressure P	inches	mean, a	°
Corrected volume V_0	cc.	tangent, a	
Current strength C	amp.	constant, K	

If battery cells are used at each table, the circuit should be opened at *R*, and a box of resistance coils inserted. By means of this the current is to be regulated, so that the galvanometer needle may indicate constantly a deflection of nearly 45°. About four Daniell or gravity cells will be needed at each table. If it is not convenient for all to begin and close the experiment at the same instant, the current may be allowed to flow all the time; and the experiment is begun at each table by quickly placing the tube over the cathode, the time signal being given at the same instant. The tube should be previously inverted in the acid, but held aside from the electrodes, so that no stray gas bubbles can enter it. The experiment may be ended similarly by removing the tube from over the electrode to its first position.

Calculations. — (*a*) The time interval is to be reduced to seconds. The barometer reading is to be corrected for temperature as in Exercise 16. The vapor pressure depends on the strength of the acid and the temperature, and may be taken from a table (see Stewart and Gee, p. 497) and given to the class by the teacher. The net pressure is the corrected barometer reading minus the vapor pressure.

(*b*) The volume is reduced to what it would be under standard conditions of temperature and pressure by substituting the observed volume, net pressure, and observed temperature for V, P, and t in the following formula for the laws of Boyle and Charles, and calculating the value of V_0, the corrected volume.

$$V_0 = \frac{VP \times 273}{30\,(273 + t)}.$$

If P is given in millimeters instead of in inches, the corresponding pressure factor in the denominator should be 760 instead of 30.

(*c*) To calculate the current, C, first find the number of cubic centimeters of hydrogen given off in one second and then divide by the number of cubic centimeters liberated by one ampere in one second, thus:

$$C = \frac{V_0}{T \times .1156}.$$

(*d*) Calculate the value of the constant, K, by the formula

$$C = K \tan a. \quad \therefore \ K = \frac{C}{\tan a},$$

in which a is the mean angle of deflection.

Sources of Error. — (*a*) The temperature of the gas may not be the same as that indicated by the thermometer.

(*b*) Time may be lost during the reversals of the current. A correction for this may be easily estimated and applied.

(*c*) The most serious errors are those arising from the imperfections of the galvanometer.

(*d*) Errors arising from the other observations have been considered in previous experiments.

NOTE. — If the teacher so directs, the corrections of the barometer reading for temperature and the corrections for vapor pressure are to be omitted.

Lessons. — This experiment teaches an important quick method of current measurement and its use in standardizing a galvanometer. The constant, K, being known, if the galvanometer is a fairly good one, the current strength corresponding to any ob-

served mean deflection may always be calculated by the formula $C = K \tan a$.

Electrical energy is a commodity. It is a most important factor in our modern industrial development. Accurate measurements of electromotive force, resistance, current strength, inductance, capacity, etc., are all for the purpose of getting at the amount of energy consumed in the various machines and appliances by which it is produced or utilized. Keep a lookout for such appliances, and try to find out how they make this energy available, and how the energy they produce or consume is measured.

Exercise Number 25

SHORT DISTANCE TELEGRAPHY

References

A 432–434	GE 379, 380	JJ 290–298
C 316	GP 550, 551	S 229
C & C 507–510, 512, 513	H 419–421, 424, 427	T 499, 500
	H & W 252	W & H 286

Purpose. — The purpose of this exercise is to set up a short distance telegraph line of two stations, to diagram the arrangement, to trace the current through the circuit, to operate the instruments, and to explain their action.

Apparatus. — (*a*) Call the two stations *A* and *B*. At each station there should be one gravity cell, one key, one sounder, some pieces of wire, and a couple of double connectors.

(*b*) A single wire representing the line wire is supported on insulators and runs from *A* to *B*.

Operations. — (*a*) At one station, *e.g.* *A*, connect the − electrode of the battery cell to a wire leading from a gas pipe or water pipe. Both wire and pipe should have been filed till bright, and the wire tightly wound a half-dozen times round the pipe, or still better, soldered to the pipe, thus securing a good "ground connection."

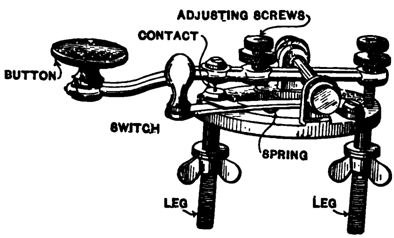

Fig. 35. — Morse Key.

(*b*) At the other station make a similar ground connection with the + electrode of the battery cell.

(*c*) At each station, connect the free electrode of the battery with one terminal of the key. Here and throughout, use double connectors where there are no binding-posts.

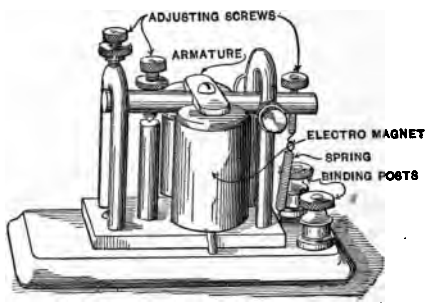

Fig. 36. — Telegraph Sounder.

(*d*) Draw a neat and legible diagram of the cell and connections as far as now made.

(*e*) At each station connect the free terminal of the key with one of the binding-posts of the sounder.

(*f*) Join the other binding-post of the sounder to the line wire. The "circuit" is now complete or "closed" and the apparatus is "in series."

(*g*) Before attempting to operate, see that both keys are closed by means of their side levers, or "switches," which are provided in order that the keys may always be closed when no message is being sent. (Why?) Now complete the diagram of the circuit, including all the apparatus at both stations and the line wire, and having due regard to the proportions of the different parts of the apparatus.

(*h*) By means of arrows, trace the path of the current from the zinc of your cell — through the fluid, then through the entire wire circuit, instruments, line, and ground — back to the zinc.

(*i*) Now operate the circuit, sending from each station in turn such Morse signals as may be indicated by the teacher.

(*j*) Make a separate sketch or diagram of the key and of the sounder. By reference to the parts as indicated by appropriate lettering briefly explain the action of each. *Draw from the objects, not the cuts.*

Precautions. — Since oxidized, greasy, or loose connections greatly diminish the current strength (Why?), see that all connections are scraped bright and clean and that the binding screws are firmly set.

Lesson. — This exercise is designed to make the student acquainted with the proper method of setting up the instruments of a telegraph line, and with the manner in which the electric current is used in sending and receiving signals with them.

Exercise Number 26

LONG DISTANCE TELEGRAPHY

References

A 432–434	GE 379–381	S 229
C 316	GP 550–552	T 499–501
C & C 511–514	H 423–425	W & H 286
	JJ 290–299	

Purpose. — The purpose of this experiment is to study the construction and action of the relay, and to learn why it is necessary on a line of high resistance.

Apparatus. — (*a*) In addition to the apparatus of Exercise 25, a relay and two more cells of battery are needed at each station.

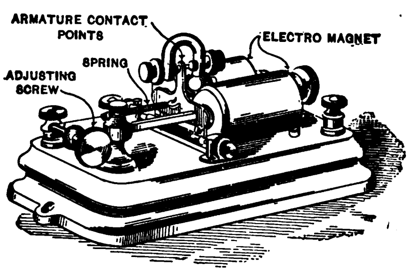

Fig. 37. — Telegraph Relay.

(*b*) The same line wire may be used, but is supposed to be many miles longer, so that the additional resistance makes the current too weak to operate the sounder. If the teacher desire, he may insert a suitable resistance to represent that of the additional line wire.

Operations. — (*a*) Examine the relay, and determine which pair of binding-posts is connected with the ends of the magnet wire. These are called the main line posts.

(*b*) The other two are called the local circuit posts. Trace the metallic paths from them to the air gap between the platinum contact point on the lever and that on the screw against which the lever strikes when the armature is attracted toward the magnet. Notice, when the armature is released and the lever flies back in obedience to the tension of its spring, that the screw against which it now strikes is insulated from it by a tip of hard rubber. Thus there is a break in the metallic path between the two local posts when the armature is not attracted; but this air gap is closed whenever the armature is drawn forward.

(*c*) If a battery cell and a sounder be placed in series with the two local posts, can the relay lever be operated by the hand, so as to act as a key, and thus to work the sounder? Why? Try it, and state what occurs.

(*d*) Now (at each table) disconnect the local wires from their posts, join two cells in series, "ground" the −electrode of this "main line battery" at station *A*, and also ground the +electrode of the main line battery at station *B*. At each station connect the other −electrode of the main line battery to one post of the key; connect the other post of the key with one of the main line posts of the relay; and join the free main line post of the relay to the line wire.

(*e*) Diagram the arrangement, and, by means of thin arrows, trace the main line current throughout the circuit.

(*f*) Send a signal from each station to the other in turn. If you fail to receive the signal, first see that the circuit is unbroken excepting at the sending key, and then, if you still fail, ask the instructor to assist you in adjusting the relay.

(*g*) Connect the local battery and sounder in series with the local posts of the relay, as you did in operation (*c*). Can you now operate the relay at *B* by opening and closing the key at *A* (the key at *B* remaining closed)? Does the relay at *A* receive signals sent from *B* in like manner? Do the relays at *A* and *B*, when thus operated, open and close their respective local circuits so that the sounders click in unison with them?

(*h*) Add the local circuits to your diagram, tracing the local battery currents through them. Use thick arrows to indicate that these currents are not the same as that on the main circuit, and are stronger.

Lessons. — (*a*) Does the relay in operation (*f*) act just as the sounder did in Exercise 25? Does it make noise enough to be heard easily, or is the noise faint compared with that made by the sounder in Exercise 25? If the main line resistance be great, can the current work the sounder when connected as in Exercise 25? Why? Is it, nevertheless, strong enough to operate the relay? Does the relay lever act like a key to the local circuit? How does it differ from a key with regard to the immediate source of the energy that moves it? Does the sounder now make noise enough to be heard easily? Is it the main battery current, *or the sound*, which is reënforced by

the use of the local battery and sounder? *State whether or not* any of the local current gets into the main circuit, or any of the main line current into the local circuits.

(*b*) From the *object*, make a careful drawing of the relay, and briefly explain its action. Do not repeat any statements made in answer to questions above.

Exercise Number 27

INDUCED CURRENTS

References

A 388, 389	GP 515–521	S 232, 233
C 229–305	H 396–398	T 222–226
C & C 480–484	H & W 259–263	W & H 313–315, 327–329
GE 356, 357	JJ 132–138, 140–142	

Purpose. — It is proposed in this exercise to investigate the laws of induced currents.

Apparatus. — The appliances consist of a coil of many turns of fine wire (secondary), and another of fewer turns of coarser wire (primary), which fits into the former; a soft iron core, a bar magnet, a sensitive galvanometer (D'Arsonval or astatic), and two cells in series.

Operations. — (*a*) Set up the galvanometer and connect its terminals by means of a shunt; touch the galvanometer terminals to the leading wires from the battery, and make note of the direction of the current which gives a deflection to the right, so that in the experiments the directions of the induced currents

may be observed by noting the directions of the resulting deflection. Remove the shunt.

(*b*) Connect the galvanometer terminals by long wires with the terminals of the secondary coil, keeping the coil and galvanometer as far apart as practicable.

(*c*) Thrust the north-seeking pole of the magnet into the secondary, note the deflection, and trace the direction of the induced current around the coil.

(*d*) From the direction of this current around the coil, determine the direction of its lines of force (Exercise 21), and state whether it caused the end of the coil into which it was thrust to be a north-seeking or south-seeking pole.

Remember that if the current circulates counter-clockwise around the coil as you face its end, the lines of force come out of it; and this end is a north-seeking pole.

(*e*) Was the force of the coil in such a direction as to oppose or to assist the motion of pushing the north-seeking pole up to the coil?

(*f*) Now withdraw the north-seeking magnet pole, and note deflection, direction of current, direction of lines of force, and effect on the motion, as before.

(*g*) Repeat all the observations and notes, using the south-seeking pole of the magnet.

(*h*) Connect the terminals of the primary coil with the battery; determine one of its poles from the direction of the current around it, or by a compass needle (Exercises 20, 21); and then repeat all the experiments and notes made with one pole of the magnet.

(*i*) Reverse the current through secondary. Does

its polarity change? Repeat all the experiments and notes as with the other pole of the magnet.

(*j*) Repeat all the experiments with the two coils, having previously placed the soft iron core inside the primary (*b*). State whether the quality or magnitude of the effects has changed, and how.

(*k*) Place the primary inside the secondary, and then (1) close circuit; (2) open circuit; (3) reverse the battery wires and close circuit; (4) open the circuit. Note all the results and compare them, quality and quantity, with those obtained by *inserting and withdrawing* the coil while the circuit *remains constantly closed.*

(*l*) Insert the primary into the secondary and the soft iron core into the primary. Now repeat all the experiments made in (*k*) and compare results.

Inferences. — State the effect produced (*a*) by increasing the number of lines of force passing in a given direction through a closed coil, (*b*) by diminishing the number of lines passing in the given direction through the closed coil (all the movements that were made either increased or diminished them). (Why?)

(*c*) State how the magnitude of the induced E.M.F. is affected by the *rate of change* of the number of lines, which was increased or diminished in the various cases either by changing *more lines* or by *quickening the motion* so as to change the same number in less time.

(*d*) State Lenz's Law, and say whether or not all the observations show that this law is verified in your experiments.

CHAPTER VI

SOUND

Exercise Number 28

SPEED OF SOUND

References

A 184	GE 180	J 18, 24, 25, 31
C 191, 192	GP 157	S 180
C & C 180, 181	H 189–191	W & H 339
	H & W 338	

Purpose. — The purpose of the experiment is to determine the speed of sound in open air.

Apparatus. — The appliances required are: (*a*) a surveyor's tape, or a bicycle with an accurate cyclometer attached; (*b*) a stop-watch; (*c*) a pistol and some blank cartridges; (*d*) two thermometers.

Place. — This must be such as to furnish a straight-away stretch of open ground, level, and uninterrupted by trees or buildings. A country road or railroad is best. Such a place can usually be reached by a car line or bicycles, even by classes in a large city.

Operations. — (*a*) Measure off as long a distance as is available, — call the two stations *A* and *B*. They must be half a mile or more apart. If there are several bicycles with cyclometers, let all measure

the distance, average the results, and reduce to feet by multiplying by 5280. If the school own a surveyor's tape, let the distance be measured by that also, and the result averaged with that obtained by the cyclometers.

(*b*) Let half the party go to station *B*, and the rest remain at *A*. Let a person at *A* set the stop-watch, and be ready to start it when he sees the puff of smoke from the pistol. When he is ready he shows a white handkerchief to the person who is to fire the pistol at *B*.

(*c*) Just before firing, *B* shows a handkerchief to *A*.

(*d*) The watch is started at the instant of seeing the puff of smoke, and stopped at the instant of hearing the sound.

(*e*) Let different pairs of students repeat the operations, the teacher standing near the observer and judging each time whether the result of the trial is worthy to be recorded.

(*f*) Now let the two parties exchange the pistol and watch; and let them make a new set of observations equal in number to the first set. The temperature should be taken several times at each station, the thermometer being screened from sun and wind.

Data.—Record in tabular form, the values of the distance, l, and of the time interval, t, observed by the first party, and of the time interval, t', observed by the second party, and of the temperature, T. Also record the average values of l, t, t', and T. Add t and t' and divide by 2 to get the mean time interval.

Calculation. — Since speed $= \frac{\text{distance}}{\text{time}}$, divide the mean value of l in feet by the mean time interval in seconds.

Sources of Error. — Since the time interval is very small, and since the percentage error of the result cannot be less than that involved in measuring the time, the errors in the measurement of l will, therefore, be relatively unimportant.

The personal equation of the observers will be the most serious kind of error, and will be apparent in the variation of the individual values of t and t' from their averages. Unless the day is perfectly calm, the wind will increase the speed of the sound if travelling with it, and diminish the speed of the sound if travelling against it.

This effect will be at least partially eliminated by observing at A and at B alternately. On account of the shortness of the time, the instrumental errors of the watch may also be serious. If the watch can be rated by reference to an accurate clock, the necessary corrections may be applied.

Temperature Correction. — Reduce the observed value of the speed of sound to what it would be at 0° C. by subtracting two feet per second for each degree that the observed temperature is above zero ($S_0 = S_t - 2t$).

Lesson. — This exercise illustrates the early methods of determining the speed of sound. In later methods the time of starting and arriving have been automatically recorded by means of the electric

current upon a sheet of paper moved by clockwork (chronograph). Thus the personal equation is nearly eliminated.

Exercise Number 29

VIBRATION FREQUENCY OF A TUNING-FORK

References

A 192–198, 201	GP 173–176	S 181, 183
C 199, 212, 213	H 186, 206–212	W & H 344
C & C 204–208, 226	H & W 335, 344	
GE 174, 192–194	J 7, 9, 39	

Purpose. — The purpose of this exercise is to rate a tuning-fork, or, in other words, to determine the number of vibrations which it makes in one second.

Apparatus. — A pendulum and a fork are mounted on supports fixed to a long board, so that, when they are vibrated simultaneously, the styluses that are attached to them will trace lines very near together

Fig. 38. — Apparatus for rating a tuning-fork.

L

along a strip of smoked glass. When the glass is drawn swiftly along the board each stylus traces a wavy line, and the line traced by the pendulum crosses and recrosses the line traced by the fork. The height of the fork above the glass, and also that of the pendulum, is adjustable by means of a clamp or screw so that the point of each stylus can press very lightly against the glass. A piano-hammer or a little mallet of soft wood is used to set the fork and pendulum to vibrating.

Operations. — (*a*) Rate the pendulum as described in Exercise 11, Part A. Record three ratings, and take their average as the number of vibrations made in one second by the pendulum.

(*b*) On a block of wood ignite a lump of camphor about the size of a pea, and, holding the glass horizontally about a half-inch above the burning camphor, move it slowly backward and forward until its under surface is entirely covered with a *thin* layer of soot.

(*c*) Now lay the glass on the board, blackened side up. The styluses should be lifted when doing this, so that they will not be bent out of their positions. The styluses should now press very lightly against the smoked glass near its end. See that the glass rests in such a position that it may be quickly pulled along the board in the direction of its length, so as to allow the fork and pendulum to trace their vibrations on it while it is moving. The speed with which the plate ought to be moved must be learned by practice, and is twice as great for a fork

making 256 vibrations as for one making 128 vibrations. (Why?)

(*d*) Set the fork and pendulum to vibrating, and slide the plate.

If the trial is successful, a set of tracings like Fig. 38 *a* will be obtained. It is well to get at least two good traces on the plate.

Each of the spaces, *ac*, *bd*, *ce*, *df*, etc., represents the time occupied by one vibration of the pendulum. (Why?) Also each space from crest to crest or from

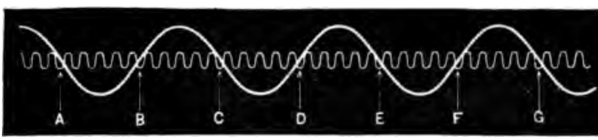

Fig. 38 *a*. — Showing the appearance of the smoked glass after taking the tracings.

trough to trough of the wavy line traced by the fork represents one complete vibration of the fork. Count the number of vibrations and tenths of a vibration of the fork traced between *a* and *c*, *c* and *e*, *e* and *g*, and so on. Make and record at least three different counts. The average of these counts is the number of vibrations made by the fork while the pendulum makes one vibration.

Data. — Tabulate the numerical data.

Let n be the number of complete vibrations which the fork makes while the pendulum is making one complete vibration; let N_p be the number of complete vibrations made by the pendulum in one second, and

let N_f be the number of complete vibrations made by the fork in one second.

Then $N_f = N_p \times n$. (Why?)

A much more accurate method of treating the observations is to count the whole number of vibrations and the fraction of a vibration that were made by the fork *while the pendulum made three or more* vibrations. Divide the former number by the latter to get the n of the above formula. In making the count it is well to mark on the glass every tenth vibration of the fork. The difficulty in applying the method suggested above lies in the fact that it is hard to get a good trace of the required length with the apparatus usually supplied.

Sources of Error. — (*a*) Since the two styluses are necessarily a little distance apart, errors will arise from changes in the speed of the plate during its motion.

(*b*) Errors are involved in estimating the fractions of a vibration.

(*c*) What errors are involved in rating the pendulum?

Lessons. — (*a*) From a table of the notes of the standard scale and their corresponding vibration numbers, choose that note to which the vibration number of the fork that you rated most nearly agrees; and call this the note given by the fork.

(*b*) See if the fork is in tune with the corresponding fork of a standard set by sounding them together and listening for "beats."

(*c*) Compare the notes given by this fork and another of *different frequency* which has been rated by another student, and state what effect the vibration frequency of a sounding body has on the note given out by it.

Exercise Number 30

WAVE LENGTH OF A TONE

References

A 205	GE 187–189	J 56, 58, 61, 62
C 173, 174	GP 168–170	S 184
C & C 191–194	H 198–202	W & H 352

Purpose. — It is proposed to determine the wave length of the tone given out by a tuning-fork.

The method consists in measuring the length of the air column that will give resonance to the fork and in deducing therefrom the length of the waves.

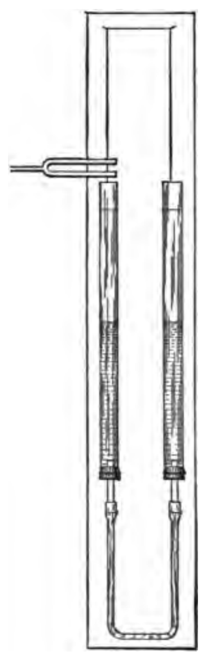

Fig. 39 *a*.

Apparatus. — (*a*) The tuning-fork should be one making not less than 256 vibrations, and preferably the one whose vibration number has been determined in the preceding exercise.

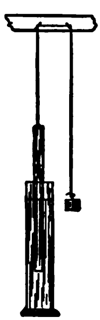

Fig. 39.

(*b*) A glass tube not less than eighteen inches long, and having an inside diameter of not less than an inch, is mounted on a suitable support and provided with a convenient means of varying the length of the column of air contained in it.

Two very convenient forms of apparatus are shown in Figs. 39 and 39 *a*. Water is used as a piston, its level in the tube being easily and accurately adjusted in the manner suggested by the illustrations.

Operations. — (*a*) Set the fork in vibration by striking it with a piano-hammer, or a little mallet made of soft wood, and place it close to the mouth of the tube in such a position that one of the prongs executes its vibrations in the line of the axis of the tube.

(*b*) Make the air column evidently too short, and increase its length until a strong resonance occurs.

(*c*) By repeated trials test the adjustment, and try to fix it between definite limits.

(*d*) When satisfied that the length of air column corresponding to maximum resonance has been fixed within the smallest limit, record the amount of this limit, and, with a rule, measure and record the length of the air column, *i.e.* the distance from the water to the end of the tube. Repeat the operations as many times as the time will permit, and record all the observations in tabular form.

Calculations. — Take the average of the numbers representing the length of the resonant air column. Theoretically, this is $\frac{1}{4}$ the length of the wave, but experiments have shown that the diameter of the tube affects the length of the resonant column. A correction equal to $\frac{1}{4}$ the internal diameter of the tube should be added to the mean length of the latter as determined above.

The wave length of the tone given out by the fork is then obtained by multiplying the corrected length by 4. (Why?)

Resonance occurs when the air column is $\frac{3}{4}$ or $\frac{5}{4}$ the wave length, but these cases are not here considered.

Sources of Error. — The most important error is that involved in the judgment of the observer as to when the loudest resonance occurs. State the distance through which the piston had to be moved each way from the position for maximum resonance before the sound became unmistakably fainter. What per cent is it of the length of the column? The percentage error of the result cannot be less than this unless the mean of a long series of observations is taken.

Lessons. — (*a*) This exercise is intended to familiarize the student with the theory of resonance, and afford practice in a simple method of directly determining wave length.

(*b*) Since a wave traverses a distance equal to its own length during one complete vibration, it is clear that the velocity of sound or the distance traversed in one second = wave length × vibration frequency. Calculate the velocity of sound from the wave length and the vibration frequency of the fork. Compare it with the velocity obtained in Exercise 28. In order to compare them, the units of length must, of course, be the same, and both values must be reduced to what they would be at 0° C., as in Exercise 28.

Knowledge of wave lengths and of the various methods of measuring them is of little *direct* practical value, but has proved to be immensely important in developing the theory of air waves and ether waves. In consequence of this theoretical knowledge musical instruments have reached increased perfection; and the discovery of wireless telegraphy became possible.

Exercise Number 31

CAUSE OF OVERTONES

References

A 199, 200	H 221, 223–225
C 200, 209	H & W 336
C & C 210, 211, 213–215, 220–222	J 54–55
GE 195, 197	S 182
GP 179–182, 185, 186	W & H 348, 356–359

Purpose. — The purpose of this exercise is to determine the positions of the nodes and segments of a musical string when vibrating under certain conditions, and to investigate the relations of these nodes and internodes to the overtones given out by the string.

Apparatus. — A sonometer, which consists of two piano wires stretched over a pair of frets at the ends of a suitable sounding-board. The wires pass over a fixed bridge near one end and differing tensions may be applied to them by means of weights or spring balances. A movable bridge is also provided. If the tensions are applied by means of weights, pulleys, or levers shaped like the quadrant of a circle, are used to change the direction of the forces from horizontal to vertical.

A violin bow, a cake of rosin, and a number of bent paper strips, to be used as riders, are also required.

If no sonometers are available, the wires may be stretched over the laboratory table; and wooden

wedges placed thereon take the place of the bridges. If spring balances are used, they may be so arranged that the tensions can be accurately adjusted by means of a pair of long screws which pull in the lines of the wires.

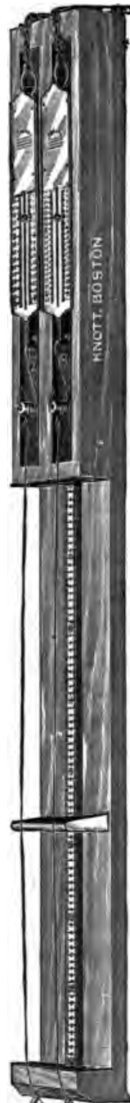

FIG. 40. — Sonometer in which the tensions are measured by spring balances.

PART A

Operations and Observations. — (*a*) See that the sonometer is securely fastened to the table by means of a clamp or handscrew, and that the tensions draw the wires in horizontal lines parallel with the length of the sounding-board. The wires should rest but lightly on the frets that are next the stretching-forces.

(*b*) Insert a movable bridge so that the length of one of the wires between the two bridges shall be (say) one meter. Now bow the wire *near* (*not at*) the middle. Can you see the part between the bridges vibrating as a whole? Apply such a tension as will cause the wire to give a full round note. Drop paper riders so that they will bestride the wire at several points along its length. What happens to the riders? What does this indicate about the condition of the wire at the places where the riders were placed?

By repeated trials ascertain whether there is any part of the wire that is not in vibration when it has been bowed or plucked near its middle point.

(*c*) Carefully listen to the tone and try to keep it in mind. It is called the fundamental tone of this string, with the given length and tension. State whether the string vibrates as a whole when it gives its fundamental tone. Where are the nodes, or stationary points? Illustrate the condition of the string and the behavior of the riders by a diagram. Write "Fundamental" beneath the diagram.

(*d*) Place riders at the ends and at the three points which divide the string into fourths. Call the riders and the points at which they are placed 0, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1. Now press, not too heavily, with the finger upon $\frac{1}{2}$ and apply the bow near 0. Immediately after the bow is removed, remove the finger also. Which riders remain quiet and which are agitated? Repeat until sure that certain riders remain quiet while certain others are violently disturbed. State the conditions of the points of the string where the riders had been placed. Illustrate by a diagram as in (*c*). Mark the nodes on the diagram. The vibrating parts between the nodes are called internodes or segments. Mark them also on the diagram.

(*e*) Repeat the operation once more and listen to the note given out by it. Compare it carefully with the fundamental by sounding first one and then the other. (To sound the fundamental, you have only to remove the finger from the point $\frac{1}{2}$.) Is it the

octave of the fundamental? If so, make another diagram and write "Octave" beneath it.

(*f*) Place riders at points 0, $\frac{1}{6}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$, $\frac{5}{6}$, and 1. Repeat the former operations, but damping with the finger at $\frac{1}{3}$ and applying the bow at point near 0. Make sure of the positions of the nodes and segments before trying the next case. Illustrate by diagram as before, marking nodes and segments.

(*g*) Listen to the tone given out by the string when vibrating as it does in this case and compare it with the fundamental and the octave. Is it the fifth (or sol) above the octave? If so, write "Fifth above the Octave" under the diagram.

(*h*) Place riders at points dividing the string into eighths and make experiments similar to the preceding. Damp at $\frac{1}{4}$ and bow near 0.

Illustrate by diagram as before, marking nodes and segments.

(*i*) Compare the resulting tone with the fundamental and first octave. Is it the second octave? If so, write "Second Octave" beneath the diagram.

PART B

(*a*) Bow the string (without damping) near the point 0, and listen carefully to the note. Can you detect the octave, the fifth above the octave, or the second octave sounding along with the fundamental? If you are *sure* that you can detect any of these, record the fact.

(*b*) Bow near 0 and *afterward* damp the wire by touching it very lightly with a feather or a bit of blot-

ting-paper at $\frac{1}{2}$. Does the fundamental cease? Do you hear the octave? If so, record the fact. Can you infer from this that the octave and the fundamental were sounding at the same time before the wire was damped at $\frac{1}{2}$? Was the wire vibrating as a whole and in halves at the same time? Why did the octave come out more clearly after damping?

(*c*) Bow near 0 and damp with the feather at $\frac{1}{3}$. Does the fundamental cease? Do you hear the fifth above the octave? Can you make inferences similar to those of (*b*)? State them.

(*d*) Bow near 0 and damp at $\frac{1}{4}$. Make a set of observations and inferences similar to those made in (*b*) and (*c*), but applying to the *second octave* and *four vibrating parts*.

Data. — Copy the tabular form and fill the blanks.

Point where bowed	$\frac{1}{2}$	0	?	?
Point where damped	—	$\frac{1}{2}$	?	?
Number of nodes	2	3	?	?
Number of segments	1	?	?	?
Resulting tone	Fundamental	Octave	?	?

Inferences. — (*a*) State whether from your experiments you are justified in inferring that a string or wire can vibrate as a whole and in parts at the same time.

(*b*) State the number of vibrating parts or segments which correspond to fundamental, the octave, the fifth above the octave, and the second octave, respectively.

(*c*) Define an overtone.

(*d*) When the tones mentioned in (*b*) are present as overtones, what is the *cause* of their presence along with the fundamental?

(*e*) State whether or not you can discern any difference in the *quality* of the tone, first when the overtones accompany the fundamental, and then when they do not accompany it.

Exercise Number 32

LAWS OF VIBRATING STRINGS — LENGTH

References

A 209, 210	C & C 210–212	H 220–222	S 186
C 215	GE 196	H & W 339	W & H 347
	GP 179	J 50–53	

Purpose. — The purpose of the experiment is to verify the law for the relation of the length of a stretched string to its vibration number.

Apparatus. — This is the same as that used in the preceding exercise. A second movable bridge is necessary.

Operations. — (*a*) Adjust the movable bridge so that the vibrating part of one wire, *A*, is (say) one meter long, and increase the tension until the wire, when bowed or plucked near the fixed bridge, gives

a good clear note. Call this note do_1, and adjust the tension and length of the other wire, *B*, so that it gives the same note. It is to be used for reference. Students who have studied music will tune the two strings to unison without difficulty. Those who have not trained musical ears can tune the second string until they begin to hear *beats*, and then cautiously shift the bridge or change the tension until the beats can no longer be heard. While the two strings are sounding together, as unison is approached, the beats diminish in number.

(*b*) Move the bridge under *A* to such a point as to make the length of the vibrating part exactly $\frac{4}{5}$ what it was at first, and sound *A* and *B* successively.

If necessary, hold the wire against the movable bridge by pressing lightly against it with the finger at a point just outside the bridge.

Repeat several times. Do you recognize the interval known in music as do_1-mi_1 (major third)? If so, record it. If the two strings do not seem to give this interval accurately, restore the bridge to its original position, and test the two strings to see if they are in tune, then repeat the operation.

(*c*) By means of the movable bridge reduce the length of the vibrating part of *A* to $\frac{2}{3}$ of its original length, and repeat the previous operations. Is the interval do_1-sol_1 (major fifth)? Test as before.

Leaving *A* of the length to sound sol_1, carefully tune *B* to unison with it (by means of its movable bridge). Now make the length of the vibrating part of *A* exactly $\frac{1}{2}$ what it was at first, and observe the

musical interval as before. Is it *sol*$_1$-*do*$_2$? If necessary, make sure by testing the two wires for unison when sounding *sol*$_1$, and repeating the observation.

(*d*) If time permits, tune B to unison with A at *do*$_2$, and then reduce the length of A to $\frac{1}{3}$. Observe and test the interval as in the previous operations to learn if the interval is *do*$_2$-*sol*$_2$.

Data. — Tabulate results as follows, appropriately filling the blanks: —

LENGTH	100 cm.	80	66.66	50	33.33
Length ratio: $\frac{\text{New length}}{\text{Original length}}$	1	$\frac{4}{5}$	$\frac{2}{3}$	$\frac{1}{2}$	$\frac{1}{3}$
New note	*do*$_1$	?	?	?	?
Interval	Unison	?	?	?	Octave + fifth
Vibration ratio of interval: new note to fundamental	1	$\frac{5}{4}$	?	?	?

Sources of Error. — Errors may arise from unobserved changes of adjustment, but the most serious error, of course, lies in the judgment of the hearer as to the accuracy of the interval. This experiment may be performed with much greater accuracy and completeness by using one string and a set of standard forks of known vibration numbers, and tuning the string to unison with each fork in turn by chang-

ing the length only. The lengths and vibration numbers can then be directly compared. This method, however, is not adapted to the equipment of most elementary laboratories.

Inferences. — Compare the ratio between each new length and the first length with the ratio between the vibration number of the corresponding new note and the fundamental. What must be done with each ratio of the vibration numbers in order to make it equal to the ratio of the corresponding lengths? State the relation of the frequencies of the notes to the corresponding lengths of the string. This is sometimes called the First Law of Vibrating Strings.

Exercise Number 33

LAWS OF VIBRATING STRINGS — TENSION

References. — These are the same as those for Exercise 32.

Purpose. — The law that states the relation of tension of a string to the vibration number is to be verified.

Apparatus. — The apparatus used in Exercises 31 and 32 is to be used in this experiment.

Operations. — (*a*) The two wires are put under tensions of about two or three pounds each. The tensions should be made as nearly as possible exactly equal. The movable bridge is then adjusted under both wires at such a distance from the fixed bridge that the vibrating parts of the two wires are of equal length. If the tensions and lengths are exactly equal,

and the diameters and materials of the two wires the same (as they should be), the two wires when sounded together will be in unison.

If beats are noticed, go carefully over the adjustments of length and tension until these adjustments are correct and the two wires are in tune.

(*b*) Increase the tension of the wire A until it is four times as great as before. If using the spring balances, do not forget to allow for the *zero correction* as in Exercises 5 and 6. Is the resulting note the octave of the first? Sound B and A successively and compare the notes. By means of a movable bridge make B half its original length, so that it will give the octave of the first note. Are the two strings again in unison? If not, go over the adjustments of tension of A and length of B, see that they are correct, and try again. If the two strings are not in exact unison, is the difference too large to be ascribed to such errors as are likely to exist in the adjustments of tension?

(*c*) Restore the two wires to their first condition and repeat all the operations, using a tension on A which is nine times as great as the first. Is the note sounded the fifth above the octave? Make B one-third its original length, and test carefully as before to see if the two strings are in unison.

Data. — Call the fundamental do_1, the octave do_2, and the fifth above the octave sol_2. Tabulate the data. If the number of vibrations per second when do_1 is sounded is n, then that corresponding to do_2 is $2n$. What is that corresponding to sol_2?

Inference. — (*a*) Compare the tensions and the corresponding vibration numbers. What has to be done with the former in order to make the latter proportional to them?

(*b*) State the law that is verified by the observations made in this exercise.

Exercise Number 34

LAWS OF VIBRATING STRINGS — DIAMETER

References. — These are the same as those for the two preceding exercises.

Purpose. — The law of the relation of vibration number to diameter is to be verified.

Apparatus. — This is the same as in the three preceding exercises, except that the two wires used should have diameters which bear a simple relation to each other. If Nos. 22 and 28 B. & S. gauge are used (or 16 and 24), the diameters will be very nearly as two to one. A vernier caliper or micrometer caliper is needed for determining these diameters.

Operations. — (*a*) By means of the movable bridge and a suitable tension, adjust the larger wire, *A*, so that it gives a clear note. Make the length and tension of the smaller wire, *B*, exactly the same, and carefully compare the two notes. Is the note given by *B* the octave of that given by *A*? If not, go over the adjustments carefully.

(*b*) Make *A* one-half the original length, and see if the two notes are in unison. Test the adjustment as in the previous experiments.

(*c*) Measure the diameters of the two wires.

Data. — Tabulate under the following heads: —

Diameter	A	B
Note	do_1	?
Frequency	n	?
Ratio $\frac{\text{Frequency } A}{\text{Frequency } B} = ?$		
Ratio $\frac{\text{Diameter } A}{\text{Diameter } B} = ?$		

Sources of Error. — Briefly state the principal sources of error.

Inferences. — (*a*) What must be done with the ratio of the frequencies in order to make a proportion with the ratio of the diameters?

(*b*) Can the lack of exact proportionality be fairly ascribed to experimental errors?

(*c*) State the law verified in the observations.

(*d*) Other things being equal, what is the relation of diameter to mass per unit length?

$\left(\text{Mass}_A = \text{volume}_A \times \text{density} = \frac{1}{4}\pi \times (\text{diameter}_A)^2 \times 1 \times \text{density, and mass}_B = \text{volume}_B \times \text{density} = \frac{1}{4}\pi \times (\text{diameter}_B)^2 \times 1 \times \text{density.} \quad \therefore \frac{\text{mass}_A}{\text{mass}_B} = \frac{?}{?}.\right)$

What, then, is the relation of the *vibration numbers* of two strings to their *masses per unit length?*

Try to find and understand applications of the laws of vibrating strings in various musical instruments.

CHAPTER VII

LIGHT

Exercise Number 35

BUNSEN'S PHOTOMETER. LAW OF INVERSE SQUARES

References

A 267, 268	GP 286–288	J 7–10
C & C 238	H 447–449	S 194
GE 223–225	H & W 276	W & H 366, 367

Purpose. — The purpose of this experiment is to verify the law of inverse squares for light by the method of Bunsen's photometer.

Apparatus. — The photometer consists of a meter rule and three square blocks, each of the same thickness as that of the rule. The blocks can slide along

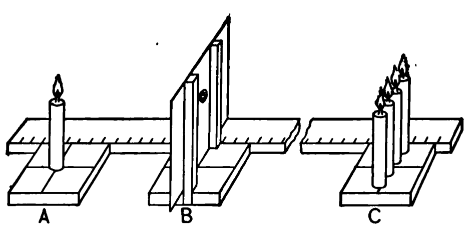

Fig. 41. — Simple form of Bunsen's Photometer.

the table beside the rule, whose face is just flush with their upper surfaces. Each block has a pair of diameters accurately scratched upon its upper surface

by means of a knife and square. One of the blocks, *B*, carries a pair of uprights, to which a screen of white paper may be attached by bits of soft wax, the centre of the screen being over the centre of the block. At the centre of this screen is a circular grease-spot (made by driving into it, with a hot flatiron, a bit of paraffin). One block, *A*, carries a single candle at its centre, and the third, *C*, a row of four candles set close together, two on each side of the centre of the block. The centres of the candles are on the diameter of the block, that is, perpendicular to the length of the rule. Shallow holes are bored into the blocks to receive the candles. The apparatus should be used in a thoroughly darkened room, and screened from the light of the other tables, or, better still, enclosed in a long box with chimneys at the ends, and with doors or opaque cloth curtains on the side toward the observer. With this latter arrangement the room need not be absolutely dark.

Operations. — (*a*) See that the five candles are all of the same height, and that their wicks are trimmed and bent down slightly, so that they give flames as nearly as possible of the same size. Trim them if necessary.

(*b*) Place the blocks *A* and *C* against the rule near its opposite ends.

(*c*) Slide the block *B* along the rule until the grease-spot ceases to be visible when seen from a point a little to the right of the edge of the screen, and read on the rule the position of the knife scratch upon which the screen rests.

(*d*) Now make a second setting in precisely the same manner, observing the spot from a position as far to the left of the edge of the screen as the first point of observation was to the right of it. Read on the rule the position of the knife scratch corresponding to the disappearance of the spot. Record the average of these two settings as the mean position of the screen.

(*e*) Read the positions of the knife scratches on the blocks *A* and *C*, and record them as the positions of the two lights. By subtraction determine the distances of the two lights from the screen.

(*f*) Change the position of one of the lights, and repeat the settings. Make as many pairs of readings as the time permits.

Data. — Record the results of each setting in a column, each result opposite its proper heading.

NUMERICAL DATA

Trials		
Readings, scratch *A*		
Readings, scratch *B*		
Readings, scratch *C* right		
Readings, scratch *C* left		
Readings, scratch *C* mean		

NUMERICAL DATA — *Continued*

Distance AB		
Distance CB		
Ratio $\frac{CB}{AB}$		
Light emitted by A	1	
Light emitted by B	4	

Sources of Error. — State the errors which may be due to (a) the candles; (b) the position of the observer, and his judgment; (c) light received by the screen from sources other than the direct rays of the candles. If *all* extraneous light be not excluded, the results will be thoroughly unreliable.

Inferences. — We assume that when the spot disappears at the mean position of the screen, the two surfaces are illuminated with equal intensities.

(a) If four candles, at distance CB, give *the same illumination to the screen* as one candle does at distance AB, what is the intensity of illumination by *one* candle at CB as compared with that by one candle at AB?

(b) What must be done with the ratio of the distances $\frac{CB}{AB}$ in order to make it equal to the ratio of the intensities with which *one candle illuminates the screen* at these two distances respectively. (Both ratios should be reduced by performing the indicated

division.) If there is a decimal remainder to $\frac{CB}{AB}$, can it fairly be ascribed to experimental error? State the law that is verified in this case.

Additional Work. — If the time assigned admits of further work, the four candles may be replaced in turn by three, two, and one, and the settings repeated. In this case, although it will not be so obvious, the ratio of the squares of the distances will be equal to the ratio of the number of candles used, as before.

Exercise Number 36

Alternative Method

RUMFORD'S PHOTOMETER. LAW OF INVERSE SQUARES

References

A 267, 268	GP 286–288	J 7–9
C & C 235–237	H 441–449	S 194
GE 223–225	H & W 276	W & H 366

Purpose. — In this exercise, the principle of Rumford's photometer is to be used to verify the law of inverse squares.

Apparatus. — A white cardboard screen is tacked to a block so as to make the card stand upright. Two square blocks, *A* and *B*, have their diameters marked or scratched on their upper surfaces, and are to be used as carriers for five equal pieces of candle. With chalk or pencil a perpendicular is drawn to the screen at its middle point. On this perpendicular,

at about 5 cm. from the screen, is mounted a small cylindrical rod. (A penholder or a lead pencil stuck into a flat cork will do.) Through the axis of the rod are drawn two straight lines, *pq* and *rs*, making

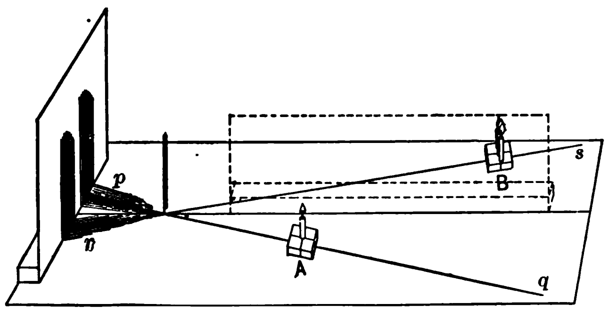

FIG. 42.—Rumford's Photometer.

equal small angles with the perpendicular and meeting the screen. On the perpendicular is placed a second cardboard screen, so as to shield the two lights one from the other.

Operations. — (*a*) At the centre of the block *A* mount one of the candles, and along the diameter of *B* mount the other four candles close together, and one behind another.

(*b*) Light the candles, bend the wicks down a little, and let them burn for a few moments till their flames are of equal size. If necessary, trim them to make them so.

(*c*) Move *A* along with a diameter on the line *pq* until the axis of the candle is, say, 25 cm. from the screen. Move the diameter of *B* along the line *rs*, and note the two shadows of the rod which are caused

by the two lights. If the black parts (umbras) of these shadows are not close together, move the screen toward the rod until they are.

(*d*) Now, with the greatest possible care, slide *B* backward or forward along *rs*, as may be necessary, until it is in such a position that the two shadows appear equally dark.

(*e*) Test the sensitiveness of the adjustment by moving the block forward or backward until each shadow in turn is manifestly less dense than the other. Record the amount of the change in distance. This represents your personal equation, or the distance within which you can set with certainty.

(*f*) Measure and record the distance from the screen to the middle of the line of four candles. Do this by measuring to the end of the block and adding half its diameter.

(*g*) Place the candles so that the line joining their centres is perpendicular to *rs* and is bisected by it. Repeat (*d*), (*e*), and (*f*).

(*h*) Change the one candle to a distance of, say, 40 cm. from the screen, and repeat all the previous operations.

Data. — Record the quantities opposite their proper headings. Make a vertical column for each setting.

Sources of Error. — State how errors may arise (*a*) in setting, (*b*) in reading distances, (*c*) in assuming that the candles radiate equal amounts of light.

Inferences. — We assume that when the shadows are equally black the screen is equally illuminated by the two lights.

NUMERICAL DATA

Settings	1	2
Distance pA		
Distance rB		
Ratio $\frac{rB}{pA}$		
Light emitted by A	1	
Light emitted by B	4	

(*a*) If four candles at the distance rB give the *same illumination to the screen* as one at distance pA, what is the intensity of the illumination by *one* candle at rB as compared with that by the one candle at pA?

(*b*) What must be done with the ratio of the distances $\frac{rB}{pA}$ in order to make it equal to the ratio of the intensities *with which one candle illuminates the screen*, at these two distances respectively? (Reduce both ratios to their lowest terms, expressing that of the distances as a mixed decimal number, if necessary.)

(*c*) Can the decimal remainder be fairly ascribed to experimental errors?

(*d*) If so, state the law that has been verified by your results.

Remarks. — This exercise can easily be performed at home in the evening, the distances being measured in inches by a foot rule or tape measure. If made in the laboratory, the room must be darkened and the apparatus surrounded by screens to cut off the light from the other tables. The Rumford photometer may be used to determine the candle power of a lamp, the calculation being similar to that of Exercise 37.

Try to find applications of the Law of Inverse Squares in the best methods of distributing artificial lights in houses and streets, and in the use of lenses and reflectors for lighthouses and searchlights. Where does the law appear in Mechanics, in Electrostatics, in Magnetism, and in Sound?

Exercise Number 37

PHOTOMETRY. CANDLE POWER OF A LAMP

References. — These are the same as those for Exercise 35.

Purpose. — It is proposed to apply the law of inverse squares in measuring the candle power of a lamp by the method of Bunsen's photometer.

Apparatus. — In addition to the Bunsen's photometer, a kerosene lamp, gas burner, or incandescent electric lamp is supplied, also a small block or adjustable support for the candle, by means of which it may be raised so that the centre of its flame shall be at the same level as that of the lamp.

Operations and Data. — (*a*) Support the candle exactly over the centre of block *A* and the lamp over

that of *B*. Trim the candle wick, and elevate the candle till its flame is level with that of the lamp.

(*b*) Make several pairs of settings exactly as in Exercise 35, tabulating the readings and distances as before. Record also the ratios $\frac{(CB)^2}{(AB)^2}$. Perform the division for the result of each trial and tabulate the results. Record the average of these results as the candle power of the lamp. By reference to the law of inverse squares and the previous exercise, explain why the ratio $\frac{(CB)^2}{(AB)^2}$ represents the candle power of the lamp.

Lesson. — This is an example of a kind of physical measurement which has an extensive application in every lamp factory and gas works.

Exercise Number 38

REGULAR REFLECTION

References

A 269–274	GE 227	J 15–19
C 330–331	GP 291, 292, 295	S 195–199
C & C 239	H 450–452	W & H 369
	H & W 283	

Purpose. — It is proposed to verify the law of reflection of light.

Apparatus. — The appliances needed are: (*a*) a small rectangular piece of plane mirror, fastened by rubber bands to a bridge nut or rectangular block; (*b*) several pins; (*c*) a rule; (*d*) a protractor.

Operations. — (*a*) Near the inner margin of the note-book page, which should be held by weights so as to be perfectly flat, draw a fine straight line, MM', and place the edge of the silvered surface of the mirror exactly upon it.

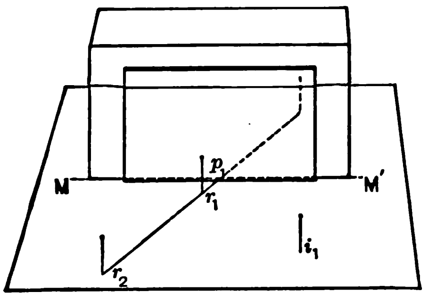

FIG. 43. — Showing how the mirror and pins are to be set up.

(*b*) Near the outer margin of the page, and a few centimeters to one side of the middle of MM', stick a pin, i_1, which may represent a luminous object and will be reflected in the mirror.

(*c*) On the other side of the middle of MM', and near the mirror, stick another pin, r_1.

(*d*) Now place the eye on a level with the page and sight along the line between the point r_1 and the point i_2 where the image of the pin i_1 appears to enter the reflected page.

(*e*) When the right position for the eye is accurately determined, stick another pin, r_2, into the page, near its outer margin, in such a position that it will exactly hide both the pin r_1 and the image, i_2, of the pin i_1.

(*f*) Remove the mirror, and with the rule draw the line r_2r_1, producing it until it intersects MM'. Mark the point of intersection, p. Also draw the

line i_1p. Then will pr_2 represent the reflected ray, p the point of reflection (and also of incidence), and i_1p the incident ray.

(*g*) At p erect a perpendicular to the line MM', and call it pq. Now, i_1pq is the angle of incidence and qpr_2 is the angle of reflection.

(*h*) With the protractor, measure these two angles.

(*i*) Repeat the experiment as many times as you can during the laboratory period. Use the same positions of the mirror and first pin, but other points for the second pin, so as to get different pairs of angles. Employ the same letters for the points; but use a *different style of lettering* for each trial.

Data. — Record results in tabular form.

DATA

Trial	Angle of Incidence	Angle of Reflection	Error	Per Cent Error

Precautions—Sources of Error.—See that the mirror does not get displaced from the line, MM'. Draw fine lines exactly through the pinholes. Sight along the points of the pins just at the surface of the page. Errors may arise from lack of planeness in the mirror, inaccuracy in placing pins and drawing lines, and in measuring the angles.

Inference. — State the law that your experiments have verified.

Exercise Number 39

IMAGE IN A MIRROR

References

A 275, 276	GE 229–236	J 20–22
C 331, 332	GP 296, 297	S 196, 197
C & C 242–245	H 453–455	W & H 370–372
	H & W 284	

Apparatus. — The appliances are the same as those in the preceding exercise.

Operations. — (*a*) Draw the line MM' across the middle of the note-book page, and place the mirror upon it precisely as in Exercise 38.

(*b*) Near a lower corner of the page draw an arrow about 4 cm. long, making an angle of about 60 degrees with MM', letter its extreme points i_1 and I_1.

(*c*) Proceeding exactly as in Exercise 38, locate as accurately as possible three reflected rays from i, and produce them behind MM', by dotted lines, until they intersect one another; obviously they should meet in a common point, i_2, which is the image of the point i_1. This point was sighted at in Exercise 38, but was not definitely located, because the lines of the reflected rays were not extended behind the mirror.

(*d*) If the lines do not meet in a point, go over the work and correct the errors.

(*e*) Similarly locate the image I_2 of the point I_1, and draw the head and tail of the reflected arrow at the points that are the images of the head and tail of the real arrow. Also join the head and tail by a straight line representing the shaft of the reflected arrow. If time permits, the middle point of the shaft should be located precisely as were the two extreme points, and it will be found to fall into a straight line with them.

(*f*) Join i_1 and I_1 with i_2 and I_2, respectively, by straight lines intersecting MM' in points a and A. Measure accurately the distances I_1A and I_2A; also measure the distances of i_1 and i_2 from a.

(*g*) Measure the angles i_1aM and i_2aM, and compare their values. Do the same for I_1AM and I_2AM. Tabulate the results as follows:—

NUMERICAL DATA

Distances and Angles		Differences	Per Cent Errors
i_1a	i_2a		
I_1A	I_2A		
i_1aM	i_2aM		
I_1AM	I_2AM		

For the per cent error of distance, find by what per cent i_2a and I_2A differ from i_1a and I_1A, respectively.

For the per cent error of angle, find by what per cent each angle differs from 90 degrees.

Sources of Error. — Small errors in placing the pins are greatly magnified in their effect on the position of the image point. The farther apart the pins are placed, the less are the errors magnified.

Inferences. — (*a*) Are the per cent differences too large fairly to be ascribed to errors of experiment?

(*b*) State the *location* of the image (as to direction and distance from the mirror) compared with that of the object.

(*c*) Compare the object and image as to *size*.

(*d*) Describe the *position* of the image (erect, inverted, or laterally inverted).

(*e*) As to *character*, is the image real or virtual?

Additional Work. — If the instructor desire, this method may be employed exactly as above, to locate and describe the image of an arrow in a concave or convex cylindrical mirror.

Exercise Number 40

REFRACTIVE INDEX

References

A 284–286	GP 303–313	J 42–51
C 335–342	H 467–473	S 207–209
C & C 256–261	H & W 300–306	W & H 381–385
GE 232–237		

Purpose. — The refractive index of glass with reference to air is to be determined.

Apparatus. — The apparatus needed consists of pins, dividers, draughtsman's triangle, rule, and a rectangular piece of plate-glass with two of its narrow parallel faces well polished.

Operations. — (a) Across the middle of the note-book page, draw a line, ss', to indicate the common surface of the glass and air. Place the glass flat upon the page, and bring the edge of one of the polished narrow faces into exact coincidence with the line ss'. The plate may be fastened in this position by bits of beeswax.

(b) Stick a pin at a point, a_1, against the edge opposite to ss' and near one corner of the plate. Place the eye opposite this pin and on the level of the page. Now look through the glass at the pin. Note the position of the eye at which the image of the pin seen *through* the glass coincides with the pin itself as seen *above* the glass. What is the direction of the line from the pin to the eye with reference to the surface, ss' ?

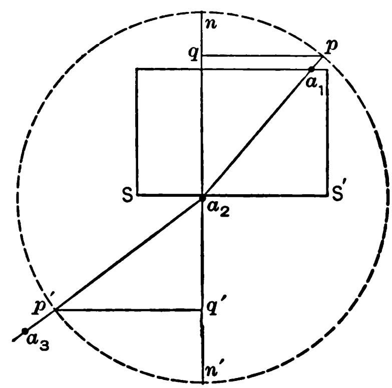

FIG. 44. — Illustrating the operations of Exercise 40.

(c) Move the eye toward one side, keeping the image of the pin in sight, and noting the change in the position of the image as referred to that of the pin itself.

(*d*) Stick a pin, a_2, against the glass, and in line with the eye and the image of the first pin.

(*e*) Near the edge of the page stick a third pin, a_3, so as to hide a_2 and the image of a_1. See that the pins are erect and accurately placed, and that the glass has not moved from its first position.

(*f*) Now remove the glass; and draw the line a_1a_2, which is the path of the ray from a_1 through the glass to the point, a_2, in the common surface, ss', of the glass and air.

(*g*) Draw also a_2a_3, which is the path of the same ray through the air, after refraction at ss'. a_1a_2 is the incident ray; a_2 is the point of incidence and also of refraction; and a_2a_3 is the refracted ray.

(*h*) Through a_2 draw nn' perpendicular to ss'. This is called the *normal* to the common surface (or interface) of the two media.

(*i*) With a_2 as a centre, and as large a radius as practicable, describe a circumference cutting a_1a_2 in point p, and a_2a_3 in point p'. (a_1a_2 and a_2a_3 are to be extended, if necessary.) From p and p' drop perpendiculars to nn', cutting it in q and q' respectively.

(*j*) Measure pq and $p'q'$ as accurately as possible in millimeters. The quotient $\frac{pq}{p'q'}$ is the index of refraction from glass to air, and this ratio inverted, *i.e.* $\frac{p'q'}{pq}$ $(= m)$, is the index of refraction from air to glass, or, in other words, the refractive index of glass referred to air.

(*k*) Repeat the operations as many times as the time will permit, using each time a different angle of incidence. Record values of $p'q'$, pq, and the refractive index, m, in a tabular form of three columns. Note also whether the values of m are equal within the limits of experimental error, and record the mean value of m.

Sources of Error. — (*a*) The edge of the glass may not exactly coincide with the line ss'.

(*b*) Errors may arise from personal equation in setting the pins; also in construction and measurement. The lines should be drawn as fine as possible with a sharp-pointed lead pencil.

Lessons. — Refractive indices are very important in the calculations according to which the lenses and prisms used in all optical work are ground. Does refraction occur if the incident ray is perpendicular to the interface? State two laws of refraction which are verified by your observations.

If R = the radius of the circle, i the angle of incidence, and r the angle of refraction,

$$\sin i = \frac{pq}{R} \text{ and } \sin r = \frac{p'q'}{R};$$

whence the Index of Refraction (*from glass to air*),

$$\frac{1}{m} = \frac{\sin i}{\sin r} = \frac{\frac{pq}{R}}{\frac{p'q'}{R}} = \frac{pq}{p'q'}.$$

In accurate measurements of indices of refraction the angles themselves are read off on an accurately graduated circle fitted with a vernier and a magnifying glass. The instrument thus used is called a spectrometer.

Additional Work. — If the student have time it will be profitable to find by trial the approximate value of the critical angle, *i.e.* the angle of incidence that corresponds to the maximum (90°) angle of refraction, and to find the image of the pin which results from total reflection of the incident waves at the surface, *ss'*.

Exercise Number 41

FOCAL LENGTH OF A LENS

References

A 290–293, 318–323	H 477–480, 513–522
C 348–350, 352, 353, 355–359	H & W 310–319
C & C 269–272, 295–304	J 60–67, 84–87
GE 238–240, 270–275	S 215–217
GP 315–320, 327, 389–391	W & H 386, 403–405, 416

Purpose. — The purpose of this exercise is to determine the principal focal distance of a convex lens, and to investigate the effect upon its focal length of combining with it, firstly, another convex lens, and, secondly, a concave lens.

Apparatus. — A metric rule is mounted on a support so that it can be turned about either a horizontal or a vertical axis. Three support blocks are fitted to the rule, as shown. The rule fits into the rectangular groove, its upper surface being flush with the upper face of the block, which is held in place by two stiff rubber bands. Wire nails are stuck upright into the block, and over them at top and bottom are stretched a pair of rubber bands, into which can be slipped a lens or a small cardboard screen. This

arrangement allows the lens or screen to rest directly against the scale divisions of the rule.

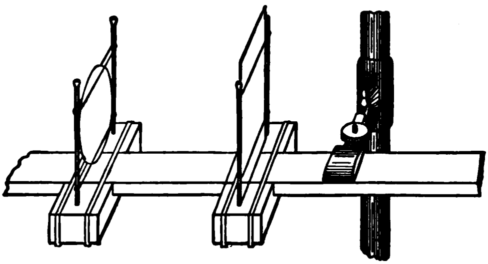

FIG. 45.—Rule and support blocks, mounted in a clamp so that they may be turned in any direction.

Two double convex lenses, unmounted, and each having a focal length of from 10 to 20 cm., and a concave lens, are provided.

Operations. — (*a*) Slip the blocks, *A* and *B*, on to the rule. Place a double convex lens between the uprights of *A* and the screen between those of *B*.

(*b*) See that the curtains are pulled about two-thirds of the way down so as partially to darken the room.

(*c*) Point the rule toward the most distant bright object that is visible through one of the windows, and, having the lens toward the window and between the latter and the screen, move the screen toward the lens or away from it until a perfectly distinct inverted image of the distant object appears upon the screen.

(*d*) Read on the rule the positions of the lens and the screen, and by subtraction deduce the distance

between them. Make at least three independent settings, changing the position of the lens on the rule each time.

(*e*) Place a second convex lens in front of the first and repeat the observations.

(*f*) Replace the second convex lens by a concave lens and repeat the operations. The two lenses should not be more than two centimeters apart.

Data. — Tabulate all of the readings. In each observation the focal length is the difference between the lens reading and the screen reading. In each case, record the average of the differences as the mean focal length of the lens or of the combination. Record the letters which are marked on the lenses, so that they may be recognized when wanted again.

Sources of Error. — From what sources may errors arise?

Inferences. — (*a*) In obtaining the principal focal distance, why should a distant object be chosen? (With a long focus lens the object should be infinitely distant, but with a lens of 10 or 20 cm. focal length, an object two or three hundred feet away will do.) (Why?)

(*b*) What two optical instruments are represented by the single convex lens and screen thus combined?

(*c*) When a second convex lens is placed in front of the first, what is the effect upon the focal length of the first lens?

(*d*) What is the effect of a concave lens? What kinds of cases of defective sight are corrected by applying the principles illustrated in (*c*) and (*d*)?

Exercise Number 42

CONJUGATE FOCI OF A CONVEX LENS

References

A 290–293, 318–323	H 477–484, 513–520
C 350–359	H & W 309–319
C & C 273–275, 295–304	J 68–80, 84–87
GE 241–246, 270–275	S 215–217
GP 315–327, 384–392	W & H 388–390, 410–416

Purpose. — The purpose of this exercise is (*a*) to investigate the conditions in accordance with which images are formed by a double convex lens, and (*b*) to verify the law of conjugate foci.

Apparatus. — The convex lens, rule, and blocks of Exercise 41 may be used, or, if preferred, the blocks of Exercises 35 and 37. In the latter case the rule should be fastened by brads to a smooth board, whose ends may be supported by blocks, at the proper height above the table. The lens and screen are to be mounted at the centres of the blocks just as in Exercise 41. The box suggested in Exercise 35 may easily be adapted to enclose either apparatus, and, if available, should be used. The rule and sliding supports as used in this and the preceding exercises constitute a very simple *optical bench.* A source of light is also provided, and may be a candle, small lamp, gas jet, or an incandescent electric lamp. It should be enclosed by a suitable opaque chimney or tube,* perforated by a circular aperture about 2 c.m.

* Fig. 46, page 190.

in diameter at the height of the centre of the light. A pin is fastened (by solder or wax) so that its head projects into the aperture from below, and is an object of which a distinct image may conveniently be obtained.

Part A

Operations. — (*a*) The focal distance of the lens is known from the preceding exercise, or may be given by the instructor. Support the optical bench so that it is horizontal and the centre of lens and screen in line with the centre of the light and of the circular aperture, the aperture being exactly at the end of the rule. Place the lens at a distance, p, greater than twice focal distance from the aperture ($p > 2f$), slide the screen up close to the lens, and, moving the screen slowly away, watch for the image to appear upon it. When the image appears, move the screen gradually backward or forward until the image of the pin is as distinct as possible. (Another lens may be used as a magnifying glass for examining the image, if desired.)

(*b*) Examine the image. Is it real or virtual? Erect or inverted? Magnified or diminished? Is it located at a distance, p', $> 2f$ (greater than twice focal distance), $p' < 2f$, or $p' = 2f$? Tabulate these observations under the headings Character, Size, Position, and Location.

(*c*) Make the distance between lens and object equal to twice focal distance ($p = 2f$), and repeat operations and observations.

(*d*) Move the lens a little toward the object, $p < 2f$, and repeat.

(*e*) In the next case make $p = f$. Note that as this distance is approached the image increases in size and becomes more distant, and when $p = f$ you would find, if a great distance were available for the screen, that no image could be formed upon it. Look *through* the lens at the luminous object from as distant a point as is available, and observe that a bright light comes from it, but no image appears. The rays approach to parallelism.

(*f*) Make $p < f$, and look toward the object through the lens for an image. Tabulate observations as before. Is the image located beyond the object or between the object and the lens?

Practical Applications. — (*a*) Which case above represents the eye, and the photographic camera?

(*b*) Which represents the projecting lens of an optical lantern?

(*c*) Which case represents the magnifying glass? In cases (*a*) and (*b*) the screen may be removed, and the image may be viewed from a point near the end of the bench that is opposite the object. A double convex lens placed at less than its focal distance from *where the screen was* will act as a magnifying glass to increase the size and distinctness of the real image. Thus the observer will see a magnified virtual image *of the real image.*

(*d*) In which of these two cases does the combination of the two lenses represent the objective and eyepiece of a compound microscope?

(*e*) In which case does the lens combination represent a refracting telescope?

Part B

Repeat the operations of cases (*a*) and (*b*), Part A, and each time read on the rule the values of the distances of object and image from the lens. These we have called p and p' respectively. Make at least two settings for each of the two cases. In one trial place the screen at the end of the rule and move *the lens* till a distinct image appears on the screen, recording the values of p and p' as before. Now interchange the object and screen without disturbing the lens; observe, and state whether or not a distinct image is formed. Record these new values of p and p'.

Data. — For each setting, take the reciprocals of p and p', expressing them decimally. Add $\frac{1}{p}$ and $\frac{1}{p'}$ for each observation. Also find the value of $\frac{1}{f}$. Tabulate the values of p, p', $\frac{1}{p}$, and $\frac{1}{p'}$, and also $\frac{1}{p}+\frac{1}{p'}$ and $\frac{1}{f}$, placing each set of values in a vertical column, under its appropriate letter, corresponding values opposite one another.

Sources of Error. — State briefly the sources from which errors may arise.

Inference. — (*a*) Experimental errors aside, are the sums, $\frac{1}{p}+\frac{1}{p'}$, equal to one another?

(*b*) Find their average. Does it differ from $\frac{1}{f}$?

(*c*) By what per cent?

(*d*) If this per cent is small enough to be ascribed to experimental errors, express the law by a general formula.

(*e*) State the law in words. p and p' are called the conjugate focal distances, and f the principal focal distance.

Exercise Number 43

STUDY OF SPECTRA

References

A 295–300, 304–309, 318–323	H 486, 487, 500–506
C 346, 360	H & W 320, 321
C & C 277–286	J 91–99
GE 249–259	S 218, 219
GP 315, 329–342	W & H 392–394, 397–402

Purpose. — In this exercise, the purpose is to investigate the composition of light emitted from different sources.

Apparatus. — In addition to the source of light and perforated chimney of Exercise 42, a prism and a Bunsen burner are provided. The perforation in the chimney is covered with a plate, having in it a narrow horizontal slit.

Operations and Observations. — (*a*) Cut out a strip of white unglazed paper, about half a centimeter wide and three centimeters long. Fasten it to a piece of black cloth or to a black photographic card-mount,

and place it in strong light from the sun or sky. Stand so that the eye is about a meter from it, and look directly at it.

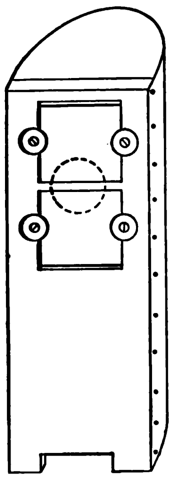

FIG. 46.—Chimney of wood and sheet iron for Exercises 42 and 43. The plates may be removed, leaving the circular aperture; or they may be pushed in from the sides, making a vertical slit.

(*b*) Now hold the prism in front of the eyes with its lower face about parallel to the line of sight, and its edges parallel to the length of the white strip. The strip will disappear; but if now the prism be raised a little without rotating, a beautifully colored image (spectrum) of the strip will be seen through the prism, apparently above where the strip is.

(*c*) Without otherwise changing the position of the prism, rotate it a little, first one way and then the other, about its axis, until the colors show with the greatest distinctness and brilliancy. This will occur at the *angle of minimum deviation;* that is, at the angle at which the light, incident on the prism from the strip,

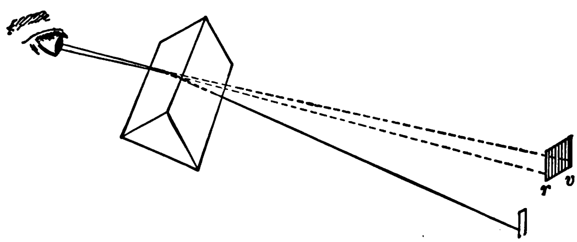

FIG. 47.—Showing position of the strip and its colored image, and the real and apparent paths of the rays.

is least turned from its original path. This position corresponds also, of course, to the minimum displacement of the image.

(*d*) Carefully examine the colors; and make a sketch of the spectrum, writing down the names of the colors in their order.

(*e*) Make a diagram of the arrangement, tracing the approximate direction which the light waves actually take in travelling from the strip to the eye, and also the directions which apparently they take in coming from the image.

(*f*) Which waves are deviated the least, those which cause the sensation of red, or those which cause the sensation of violet? Number the colors on the spectrum sketch in order, from the least deviated to the most deviated. What is the original source, and also the immediate source, of the waves which are thus separated? Why are their directions changed, some more than others?

(*g*) Place a second prism between the first prism and the eyes, the second being inverted as shown in Fig. 48. What is the effect? Are the waves recombined? What is "white light"?

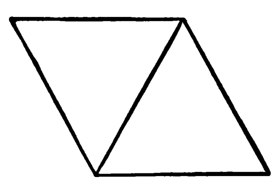

FIG. 48.

(*h*) Now place the lamp inside the chimney, the light opposite the horizontal slit and close to it, the room having been darkened. Find and examine the spectrum of the light coming through the slit, comparing it with that previously

given by reflection from the strip of paper. This is the spectrum from *white-hot carbon.* A stick with a spark on the end of it, or the filament of an incandescent electric lamp without the slit, will give the same result.

(*i*) Replace the lamp by the Bunsen burner, and after making sure that the part of the flame opposite the slit is colorless, let another student hold in the flame *below the slit* a platinum wire loop which has been moistened with distilled water and dipped into common salt or baking soda. Examine the spectrum, which is due to *sodium vapor.* What color appears most prominently?

(*j*) In like manner examine the spectra given by incandescent vapors of two or three other metals. The chemically pure bromides or chlorides of any of the following metals may be provided: potassium, calcium, strontium, and barium. Compare the colors and their relative positions. Does each metal have its own set of colors? Do they have the same positions as the corresponding colors in the solar or the carbon spectra?

Caution. — There should be a separate labelled platinum loop for each salt, and the greatest care should be exercised in order not to mix the salts; else the spectrum of the metal under examination will contain the colors of some other metals. It is extremely difficult to exclude the sodium band, because sodium is everywhere in the dust of the room. The sodium band will flash out whenever anything is dusted near the flame. Try it.

Lessons.—With suitably delicate apparatus (spectroscope), may the vapor spectra of some metals be used for detecting with certainty the presence of these metals in compounds? In the spectroscope a combination of lenses is used in order to make the light pass in a parallel beam from the slit to the prism, and to make the refracted images of the slit more distinct. Each colored image of the slit then appears as a fairly distinct band, and in a position which is perfectly definite for a given prism and for that particular wave length of light. The lack of distinctness of the bands in the case of the prism, when used without the lenses, is due to the overlapping of the images of the slit when radiations of different wave lengths are present.

If time is given for additional work, try the effect of viewing the carbon spectrum or the solar spectrum through pieces of colored glass, and state in your notes which colors are absorbed and which are transmitted by glass of each color examined.

Read the sections on spectrum analysis in the reference books to which you have access.

Twiss, G.R.
Laboratory exercises in physics.

NAME	DATE	NAME	DATE